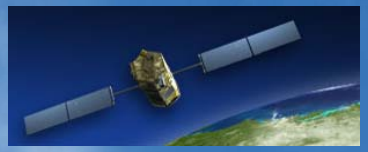
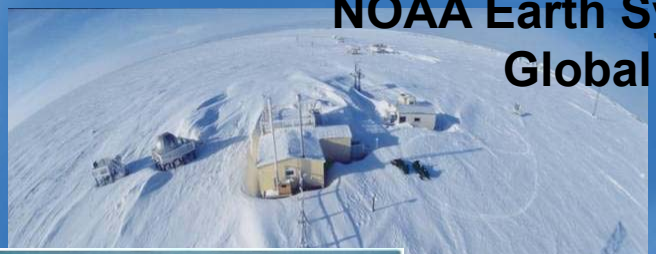
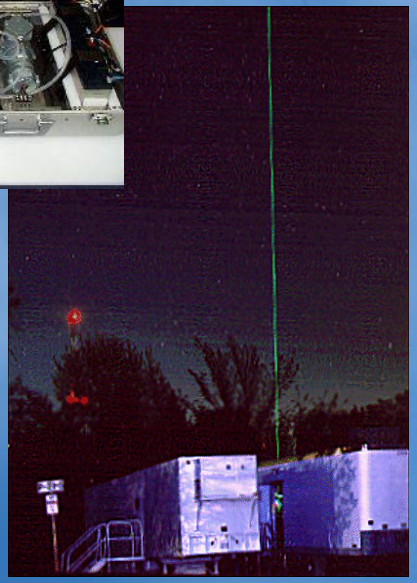
Quantification of Greenhouse Gas Emissions: A NOAA Perspective



Dr. Arlyn E. Andrews
NOAA Earth System Research Laboratory
Global Monitoring Division





E-mail: Arlyn.Andrews@noaa.gov

5th Annual California Climate Change Conference, 8-10 Sept 2008

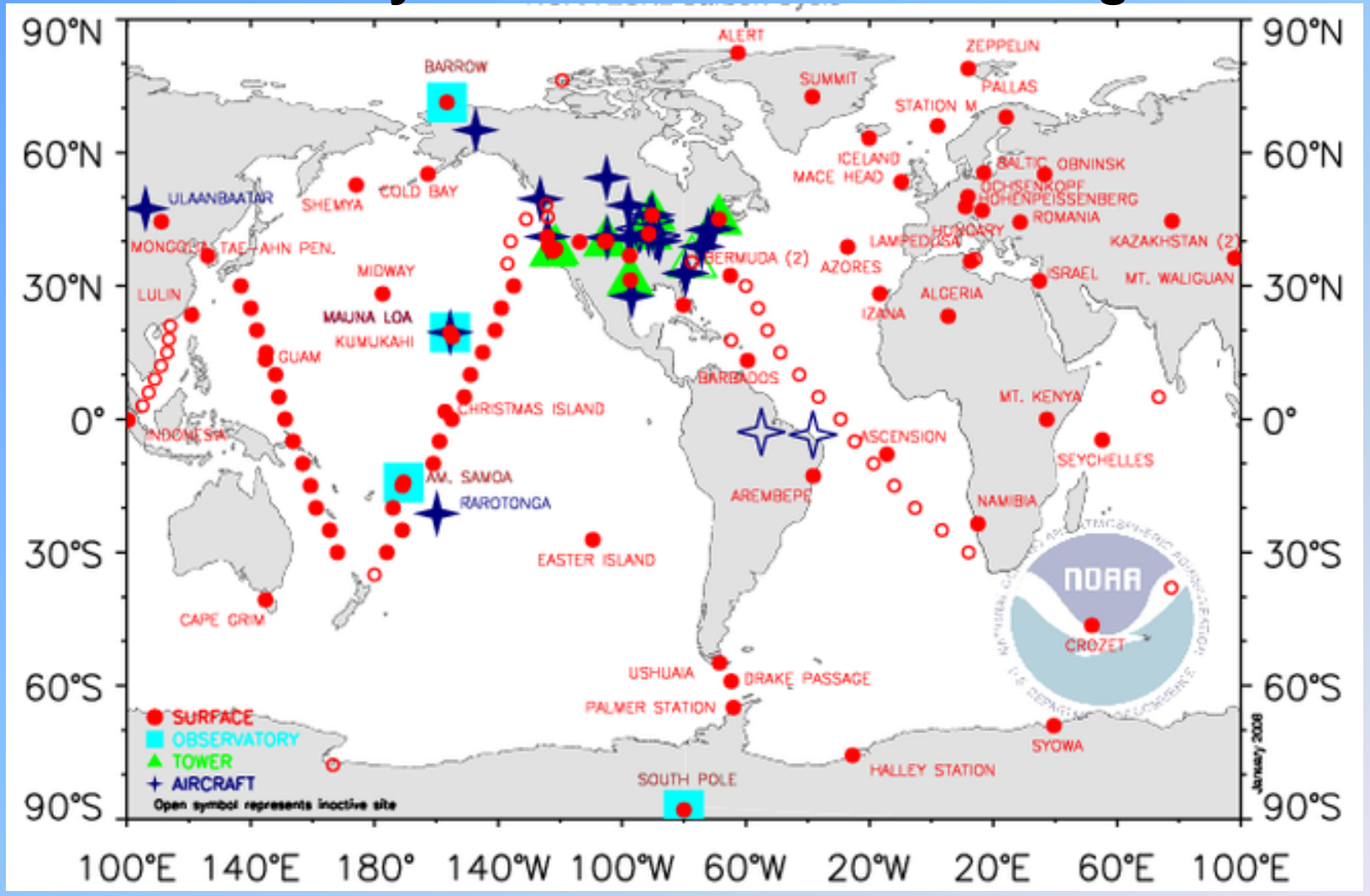
•Atmospheric concentration measurements are critical for understanding the sources and sinks of long-lived greenhouse gases. Examples: CO_2, CH_4, N_2O, SF_6

•Objective, independent evaluation of inventories will be needed to verify emissions changes if international GHG emissions reduction targets are implemented.

- CO_2 emissions inventories for the US are likely highly accurate, but globally are less reliable
- "Top-down" estimates of emissions provide independent check on inventories for CO_2 and other GHGs with poorly known sources (CH_4, N_2O, etc.).

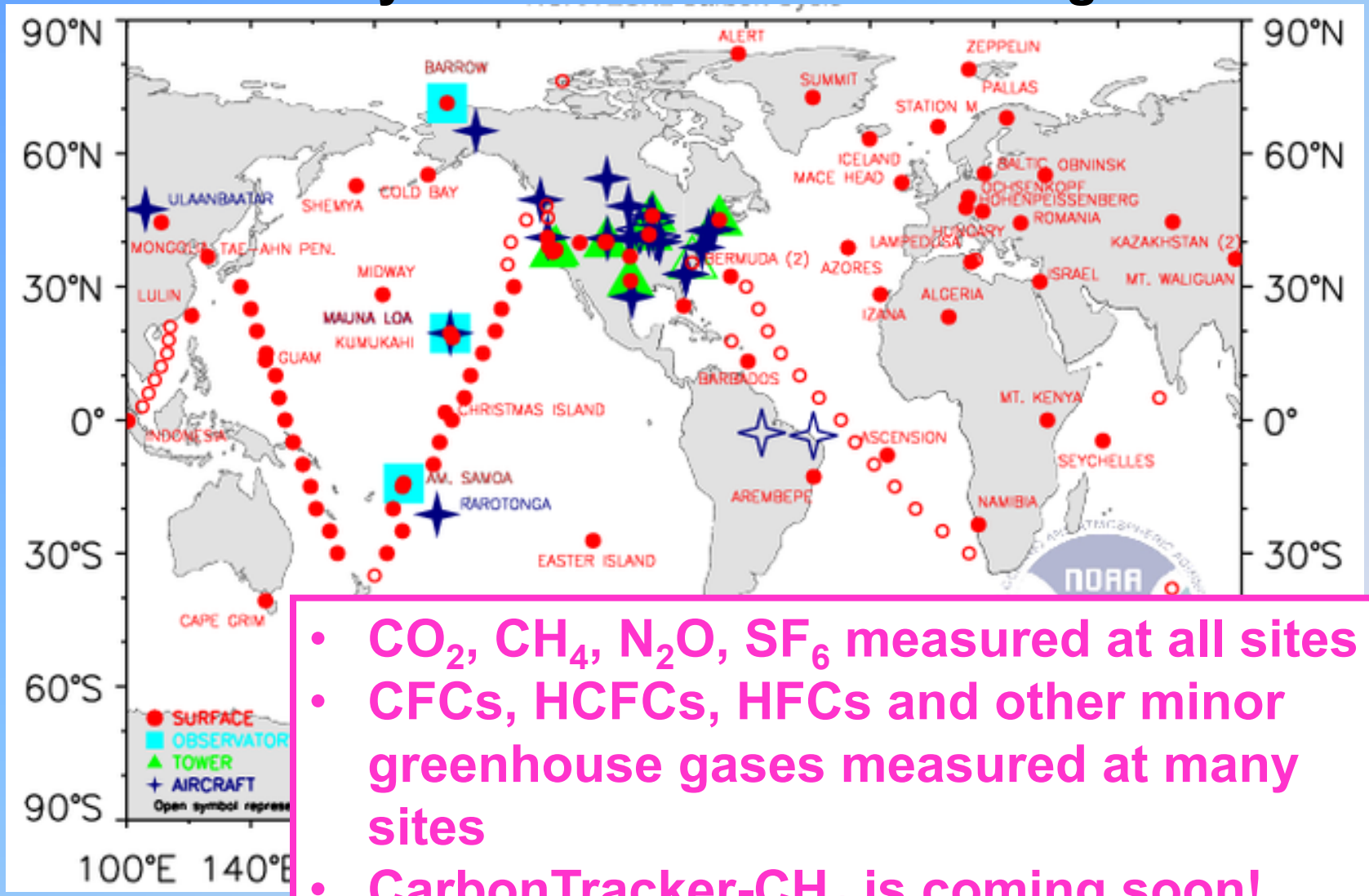
•Highly precise and accurate long-term measurements of atmospheric abundance are essential to quantify future spatial and temporal changes in emissions

NOAA Earth System Research Laboratory
Carbon Cycle/GHG Measurement Programs

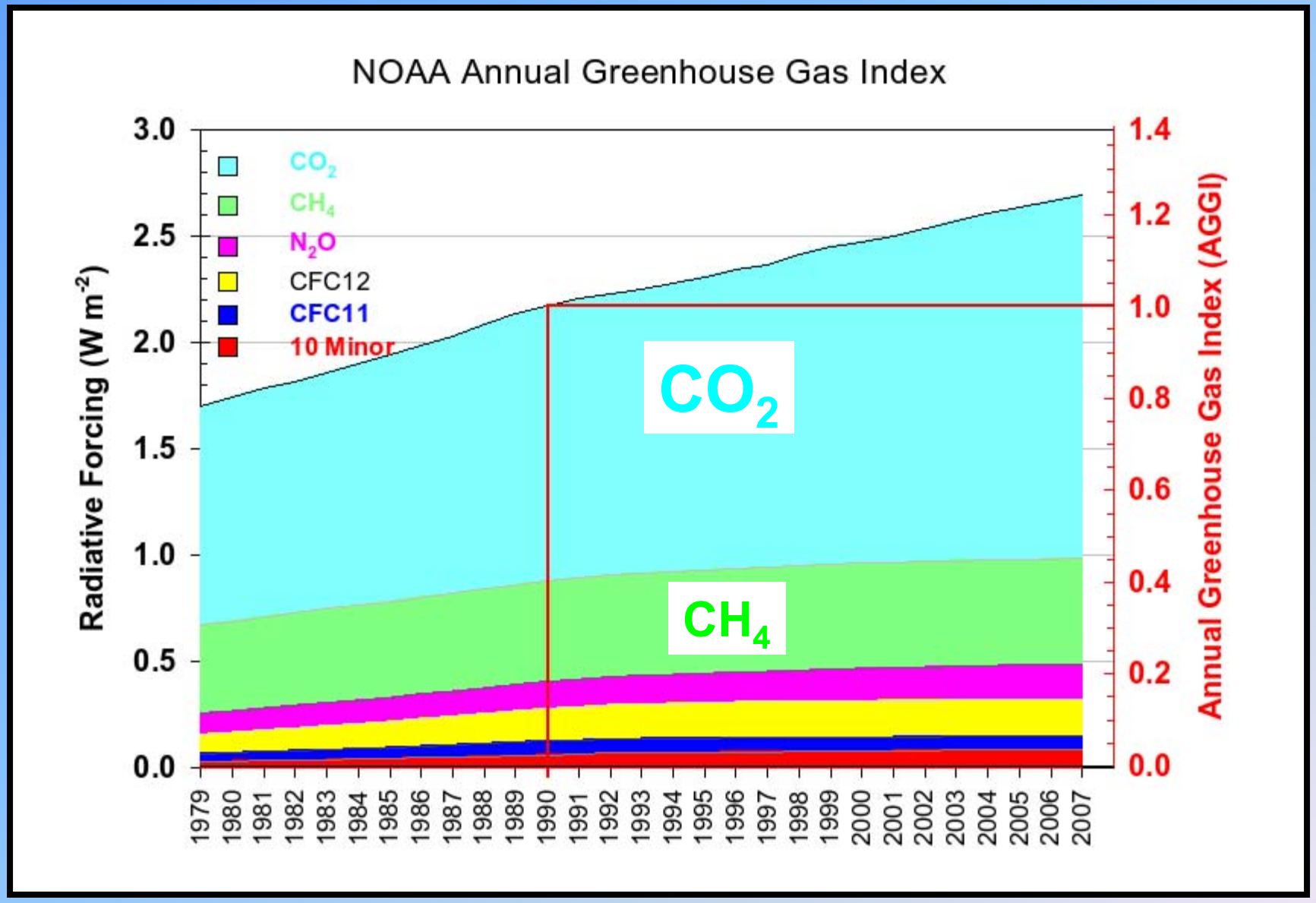


Tower | Aircraft | Flask | Observatory

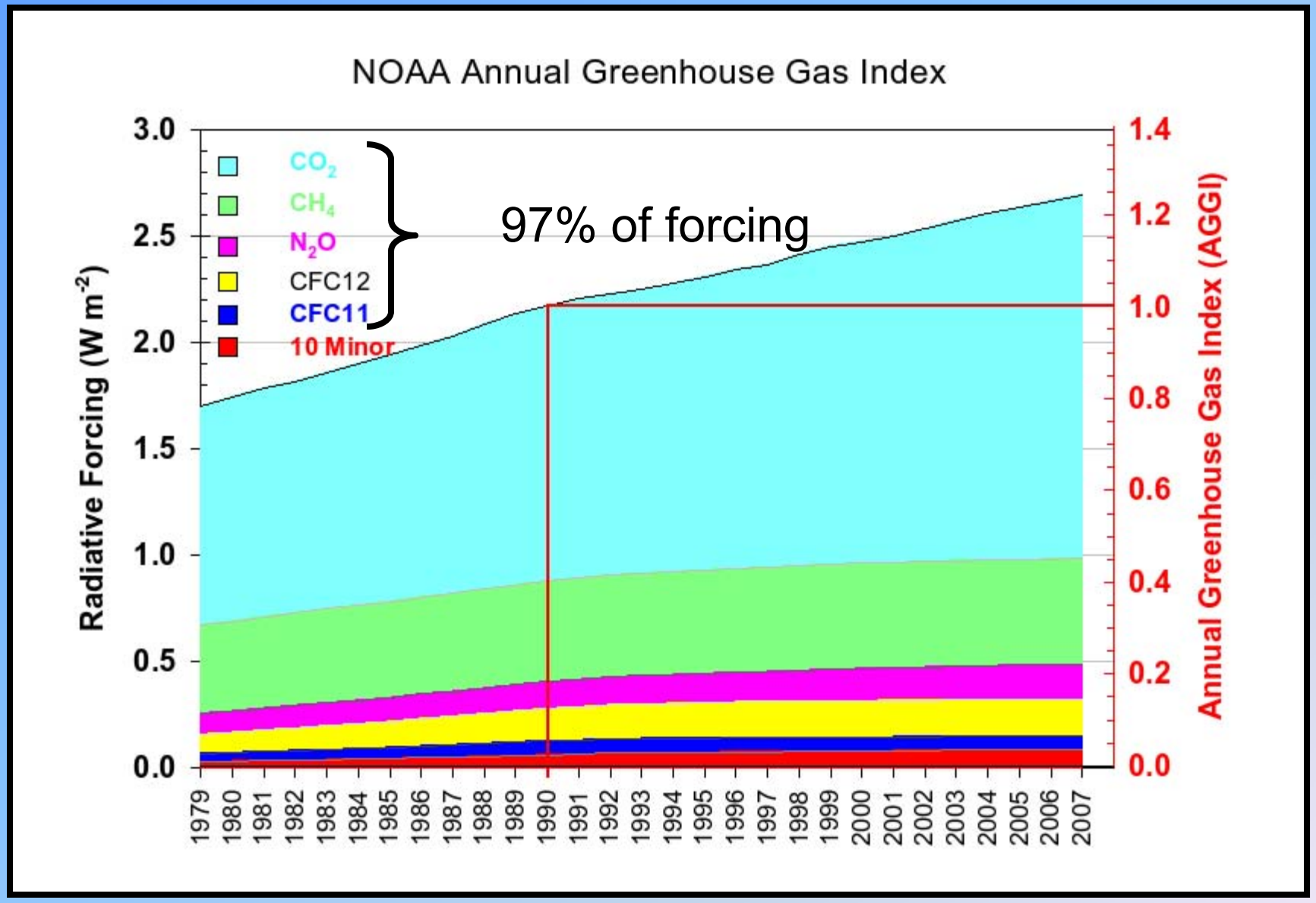
NOAA Earth System Research Laboratory
Carbon Cycle/GHG Measurement Programs



- CO_2, CH_4, N_2O, SF_6 measured at all sites
- CFCs, HCFCs, HFCs and other minor greenhouse gases measured at many sites
- CarbonTracker-CH_4 is coming soon!



http://www.esrl.noaa.gov/gmd/aggi/


NOAA Annual Greenhouse Gas Index
Radiative Forcing (W m-2)
Annual Greenhouse Gas Index (AGGI)
CO2
CH4
N2O
CFC12
CFC11
10 Minor
97% of forcing
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1979
1980
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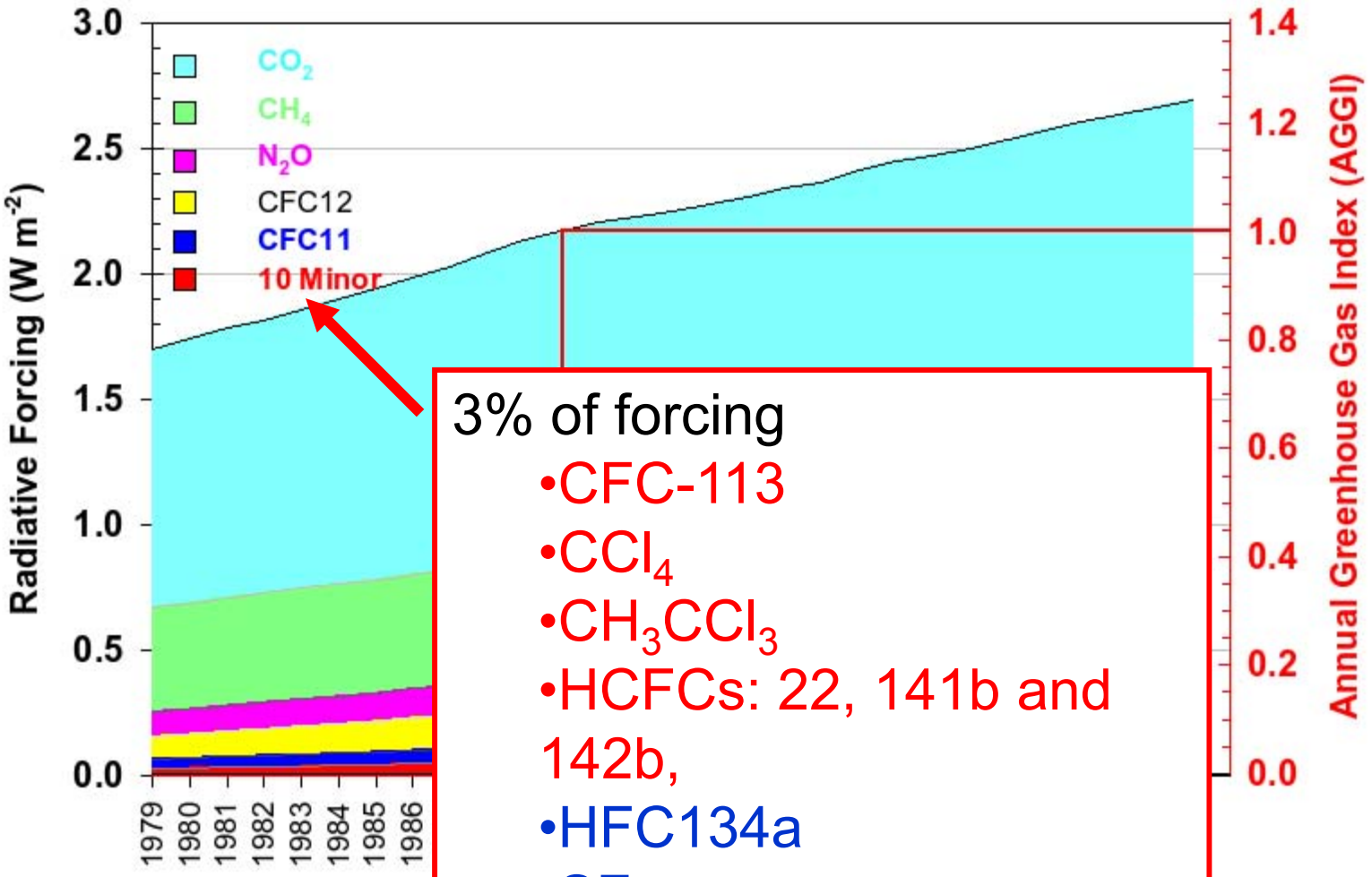
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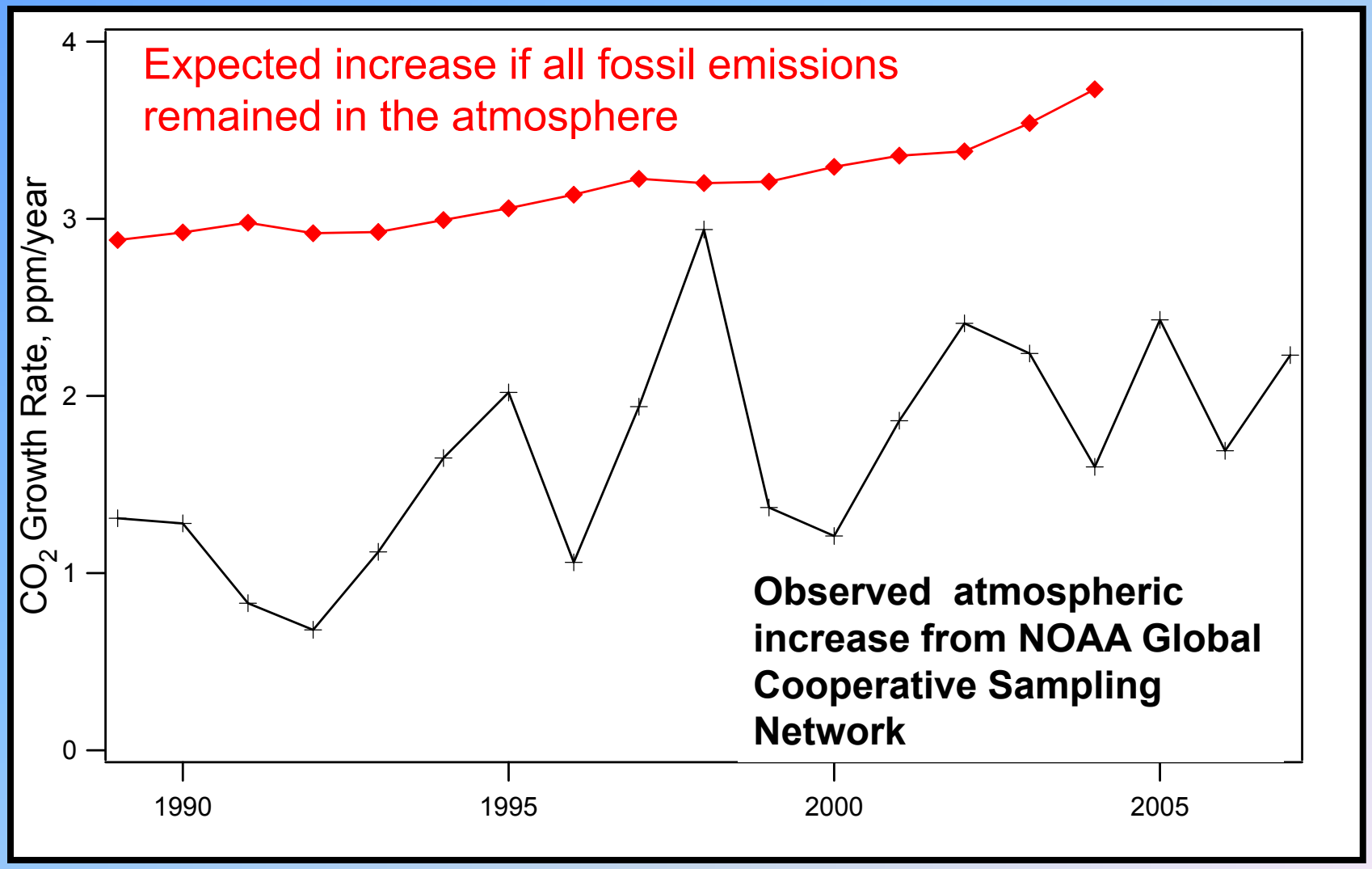
0.8
0.6
0.4
0.2
0.0
1979
1980
1981
1982
1983
1984
1985
1986
CO2
CH4
N2O
CFC12
CFC11
10 Minor
3% of forcing
•CFC-113
•CCl4
•CH3CCl3
•HCFCs: 22, 141b and 142b,
•HFC134a
•SF6
•Halons: 1211 and 1301

CO_2: Land and ocean are large sinks



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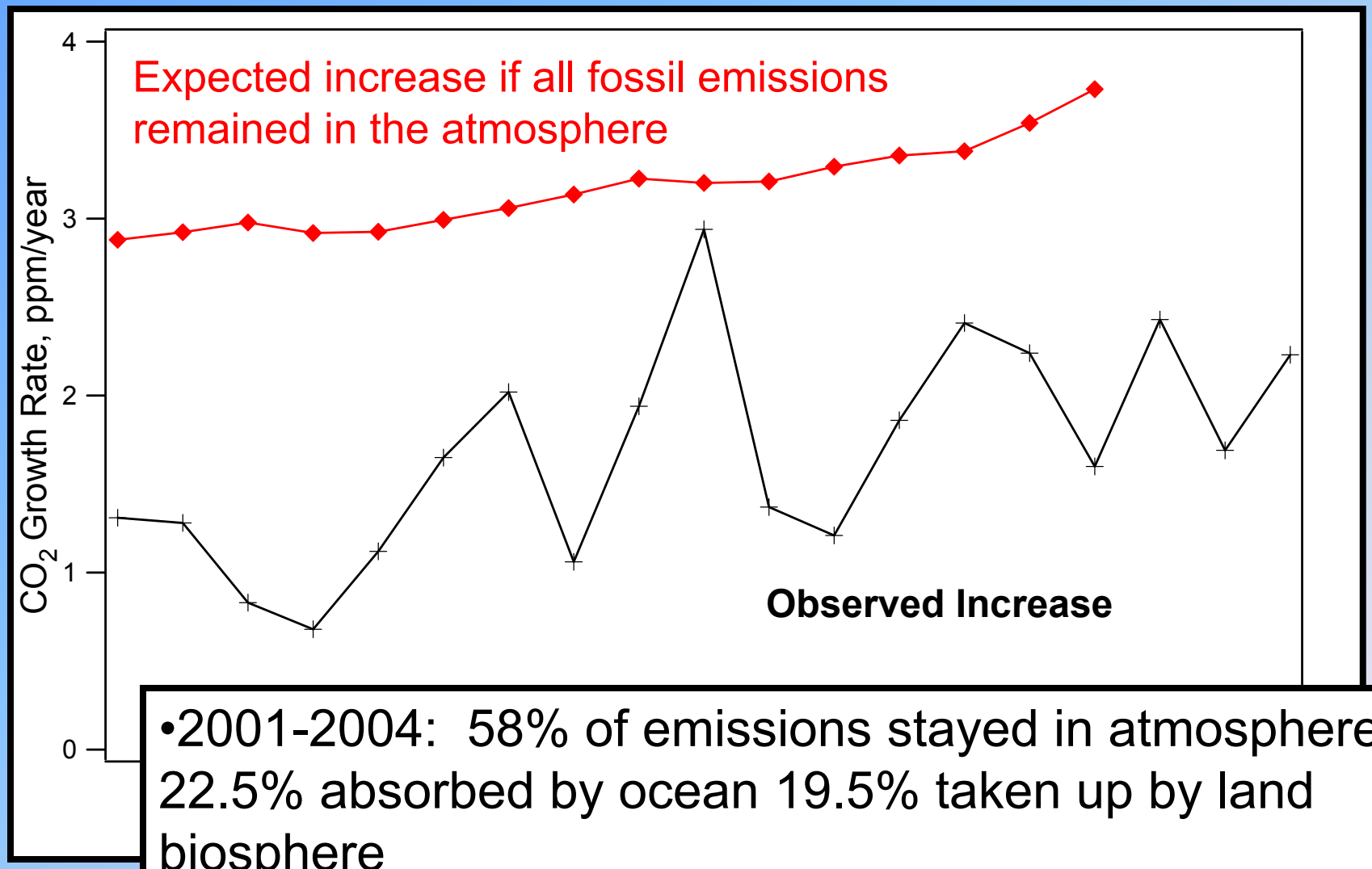
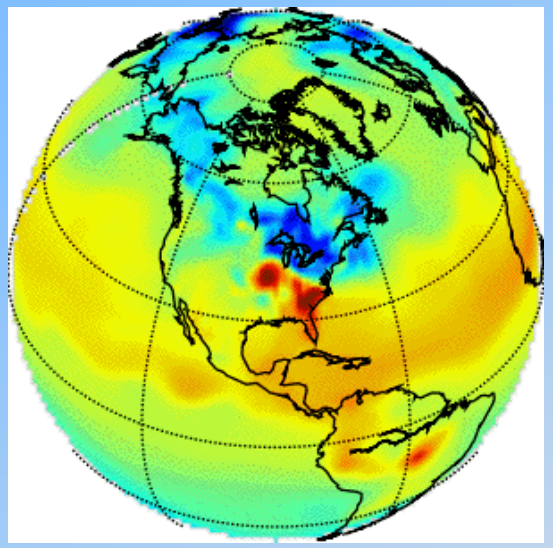


- 2001-2004: 58% of emissions stayed in atmosphere
  22.5% absorbed by ocean 19.5% taken up by land biosphere
- Emissions inventories don't tell the whole story

NOAA's CarbonTracker

- Observing Network
- Data Assimilation Framework

carbontracker.noaa.gov



PNAS

An atmospheric perspective on North American carbon dioxide exchange: CarbonTracker

Wouter Peters*†‡, Andrew R. Jacobson*†, Colm Sweeney*†, Arlyn E. Andrews*, Thomas J. Conway*, Kenneth Masarie*, John B. Miller*†, Lori M. P. Bruhwiler*, Gabrielle Pétron*†, Adam I. Hirsch*†, Douglas E. J. Worthy§, Guido R. van der Werf¶, James T. Randerson‖, Paul O. Wennberg**, Maarten C. Krol††, and Pieter P. Tans*

*National Oceanic and Atmospheric Administration Earth System Research Laboratory, 325 Broadway R/GMD1, Boulder, CO 80305; †Cooperative Institute for Research in Environment
¶Faculty of Earth and Life Sci
California, Irvine, CA 92697;
Institute of Technology, Pasa

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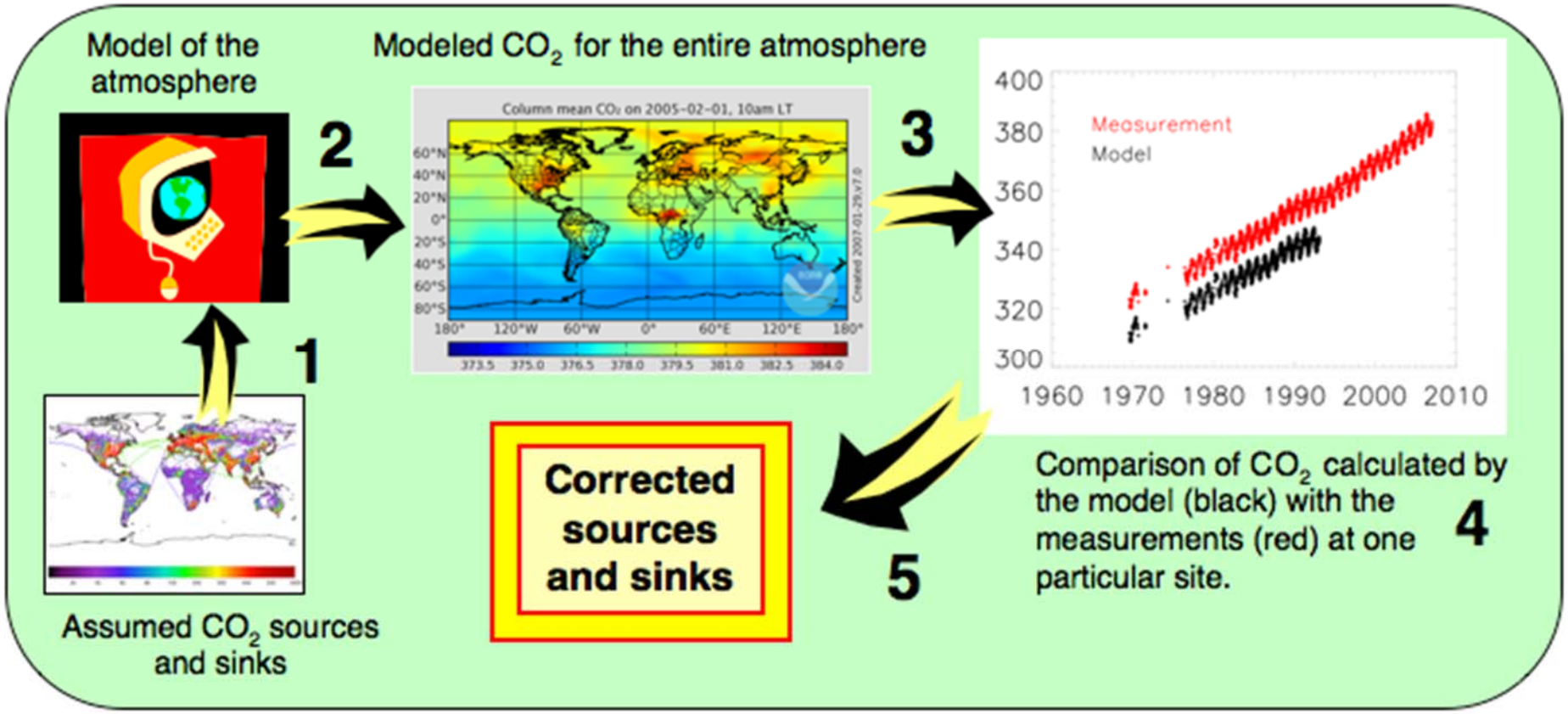
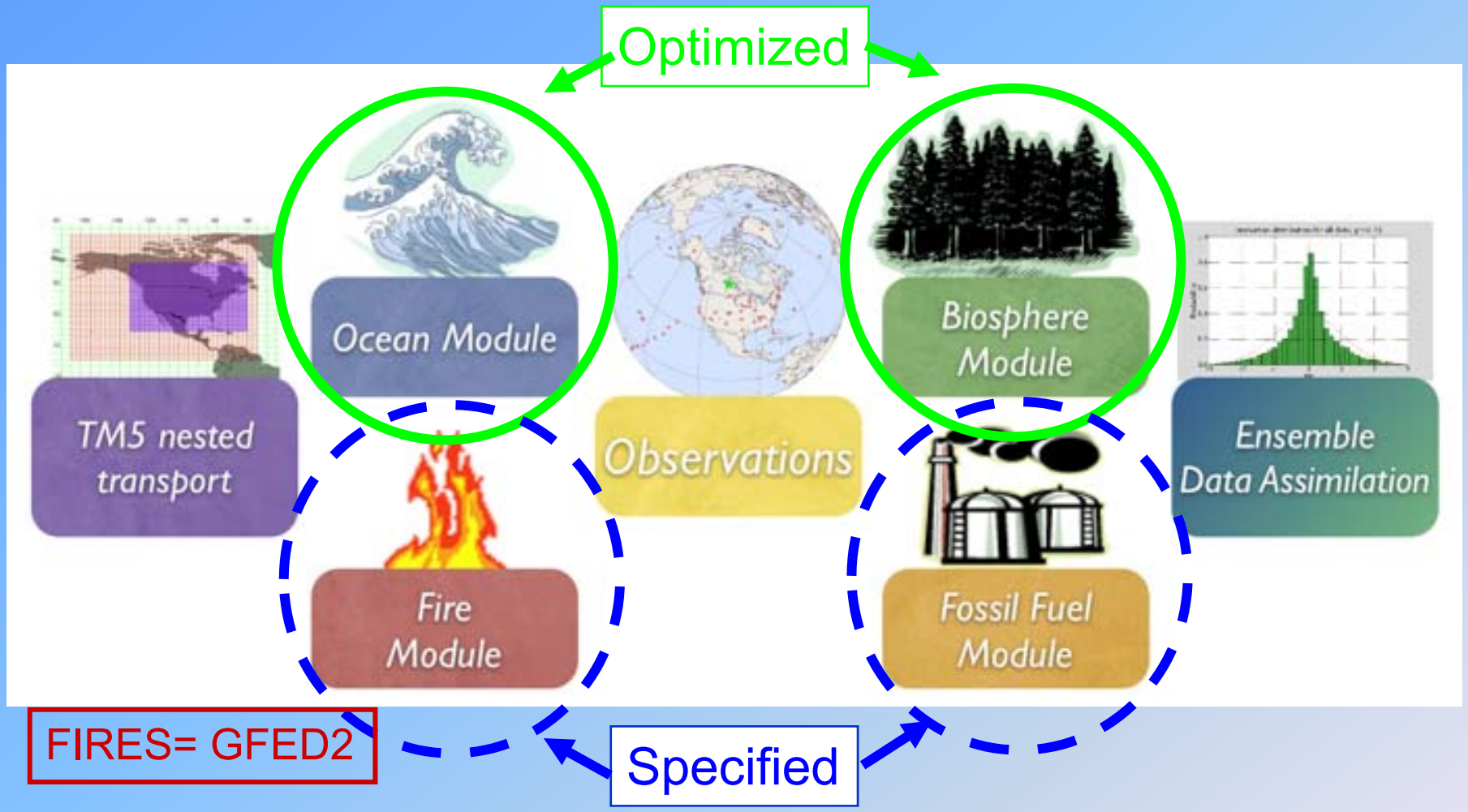
CarbonTracker Overview:



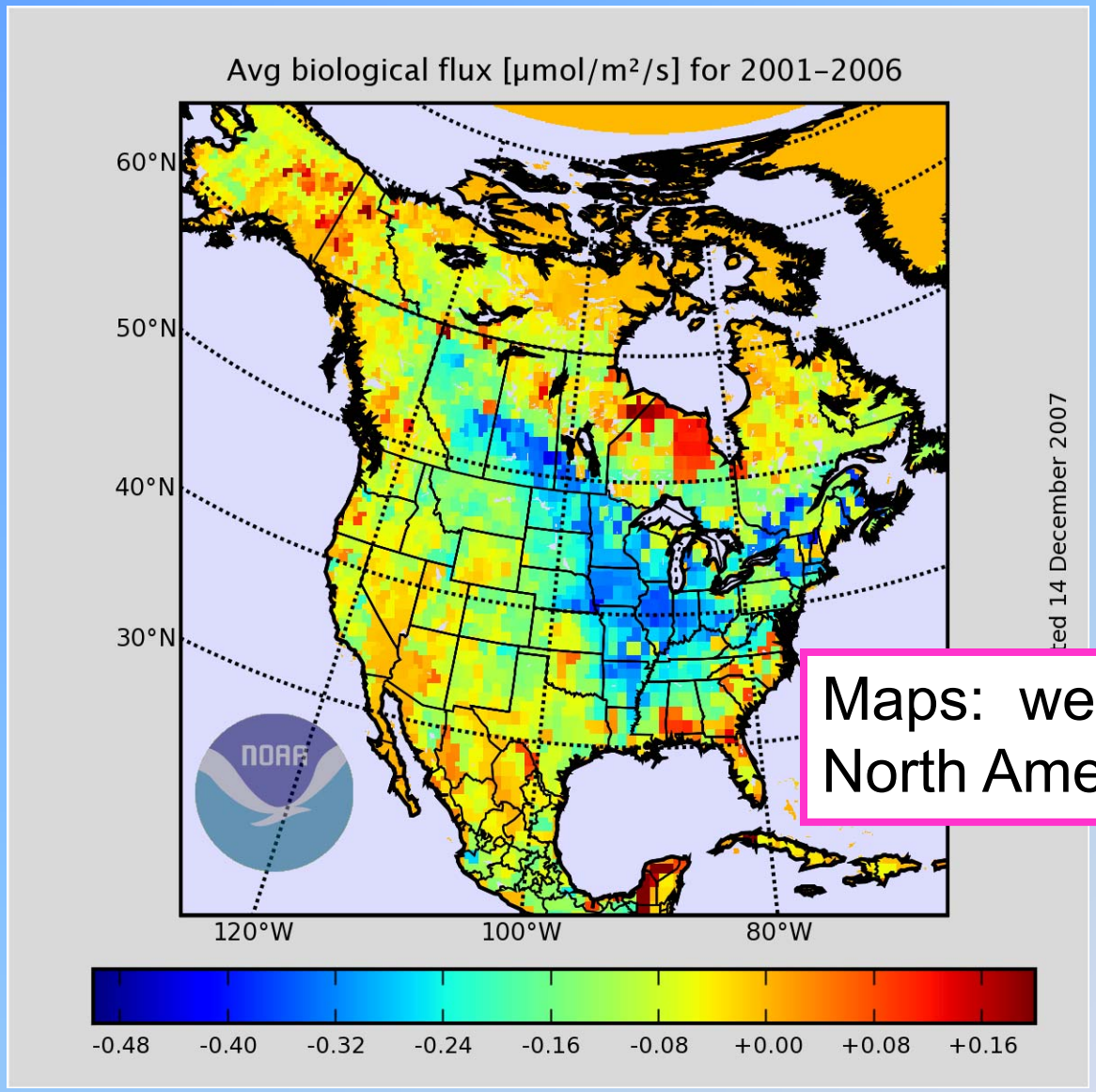
Optimization step is Ensemble Kalman Filter

CarbonTracker Mechanics:



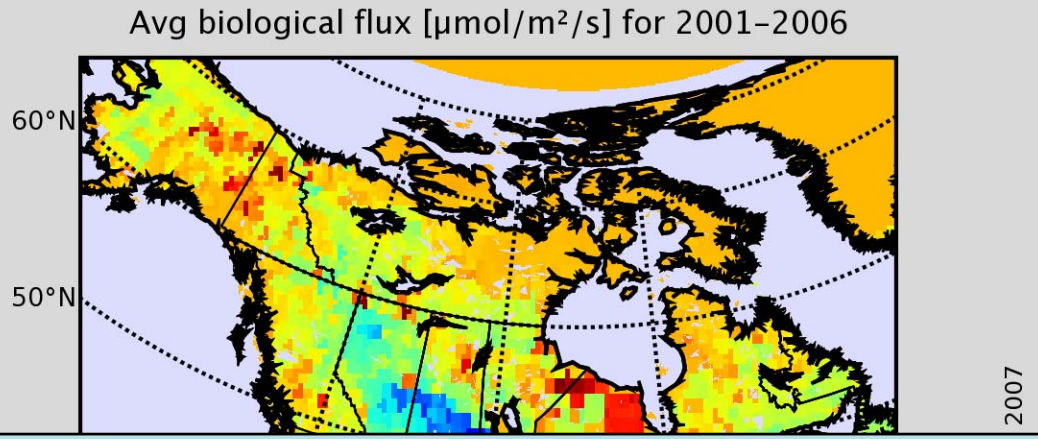
http://carbontracker.noaa.gov

CarbonTracker Products:



Maps: weekly, monthly, annual
North America and Global

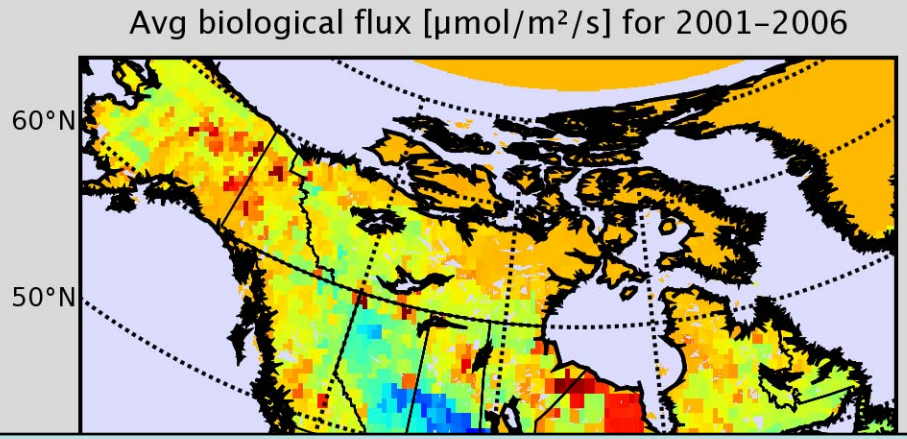
CarbonTracker Products:



Tablulated results: e.g., Jan 1-6 2000

Region Name	Estimated Mean	Fossil Emissions	Fire Emissions	Total Flux
Total North America	2.73 ± 0.60	2.14	0.01	4.88 ± 0.60
Boreal North America	0.72 ± 0.21	0.01	0.00	0.74 ± 0.21
Temperate North America	2.01 ± 0.53	2.12	0.01	4.14 ± 0.53

CarbonTracker Products:



Tablular output: e.g., Jan 1-6 2000

Region Name	Estimated Mean	Fossil Emissions	Fire Emissions	Total Flux
Temperate North America	2.01 ± 0.53	2.12	0.01	4.14 ± 0.53

Model output available for download:
Gridded 4-dimensional CO_2 fields 6-hourly avg
Gridded 3-hourly average fluxes
(global 6x4 degrees, North America 1x1 degrees)

Automated Flask Sampling from Aircraft:

- One twelve-pack per flight
- Typical profile from 500 m AGL to 8000 m ASL
- Species: CO_2, CO, CH_4, N_2O, SF_6,
  stable isotopes, halocarbons, COS, hydrocarbons…
  $^{14}CO_2$ on a limited number of samples

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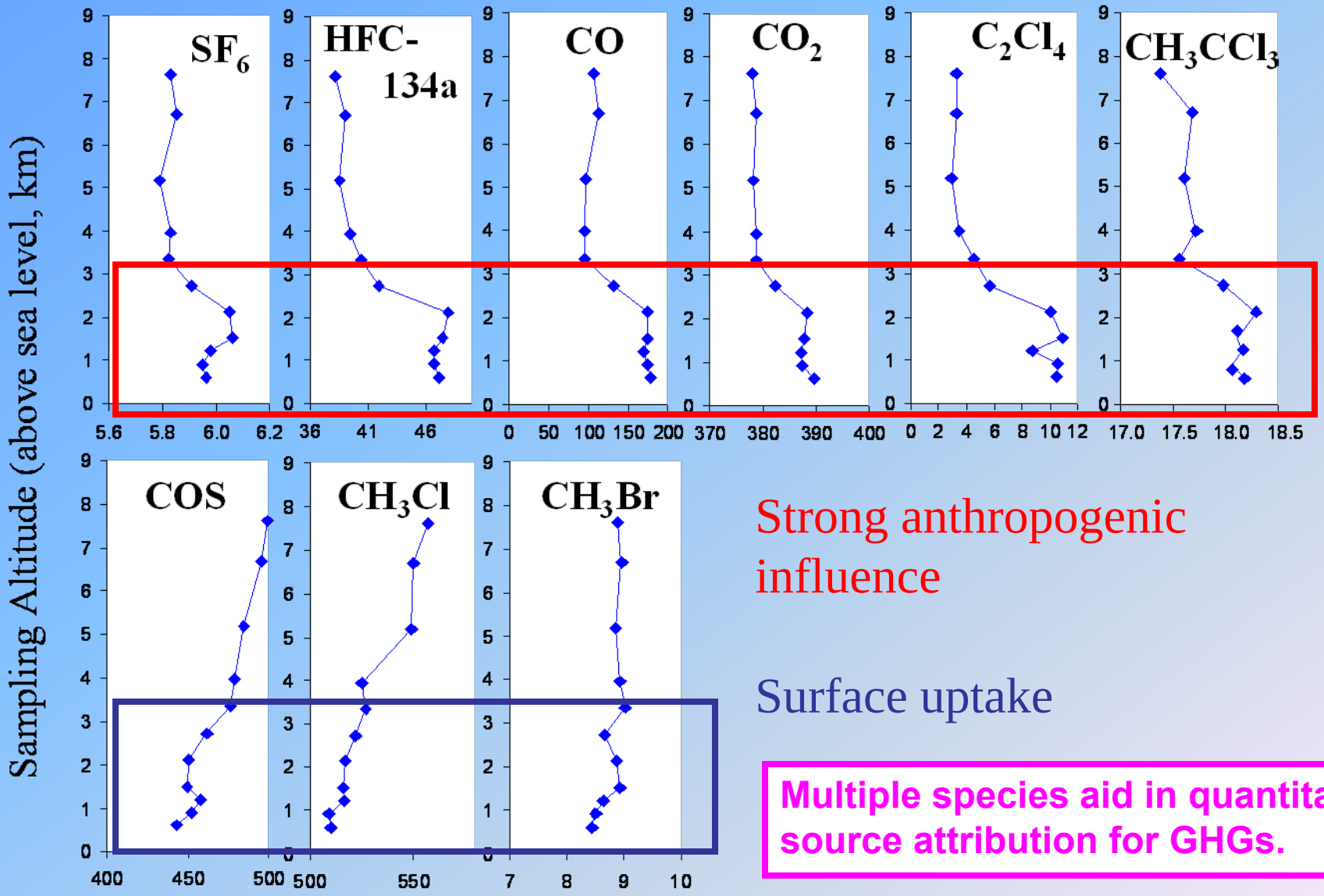
  $^{14}CO_2$ on a limited number of samples

Radiocarbon is uniquely valuable tracer for CO_2 from fossil fuel combustion—fossil fuels contain no $^{14}CO_2$ ($\tau_{1/2}$=5730 yrs)

Multiple species analysis:

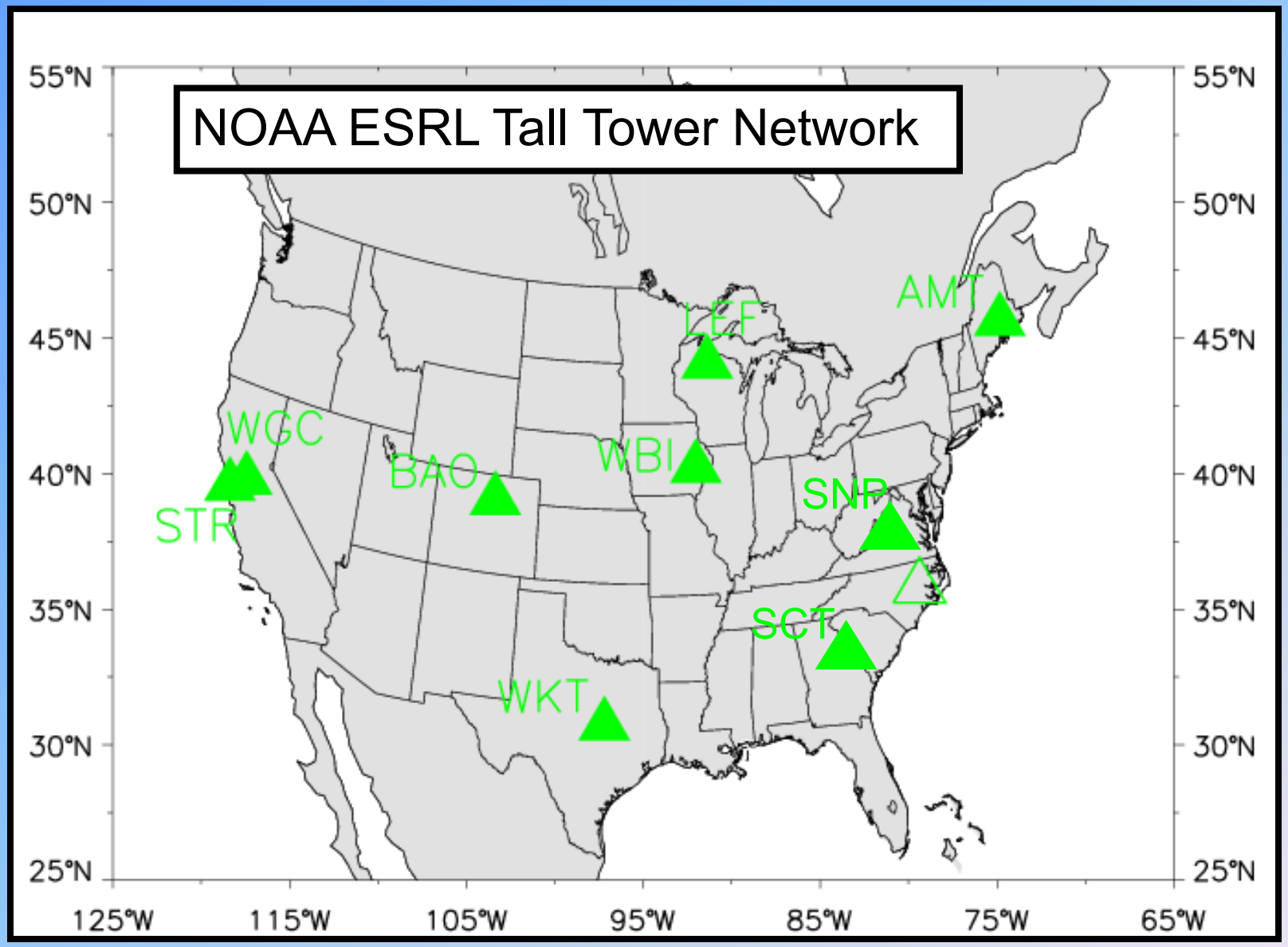
Eastern USA
Nov 2005

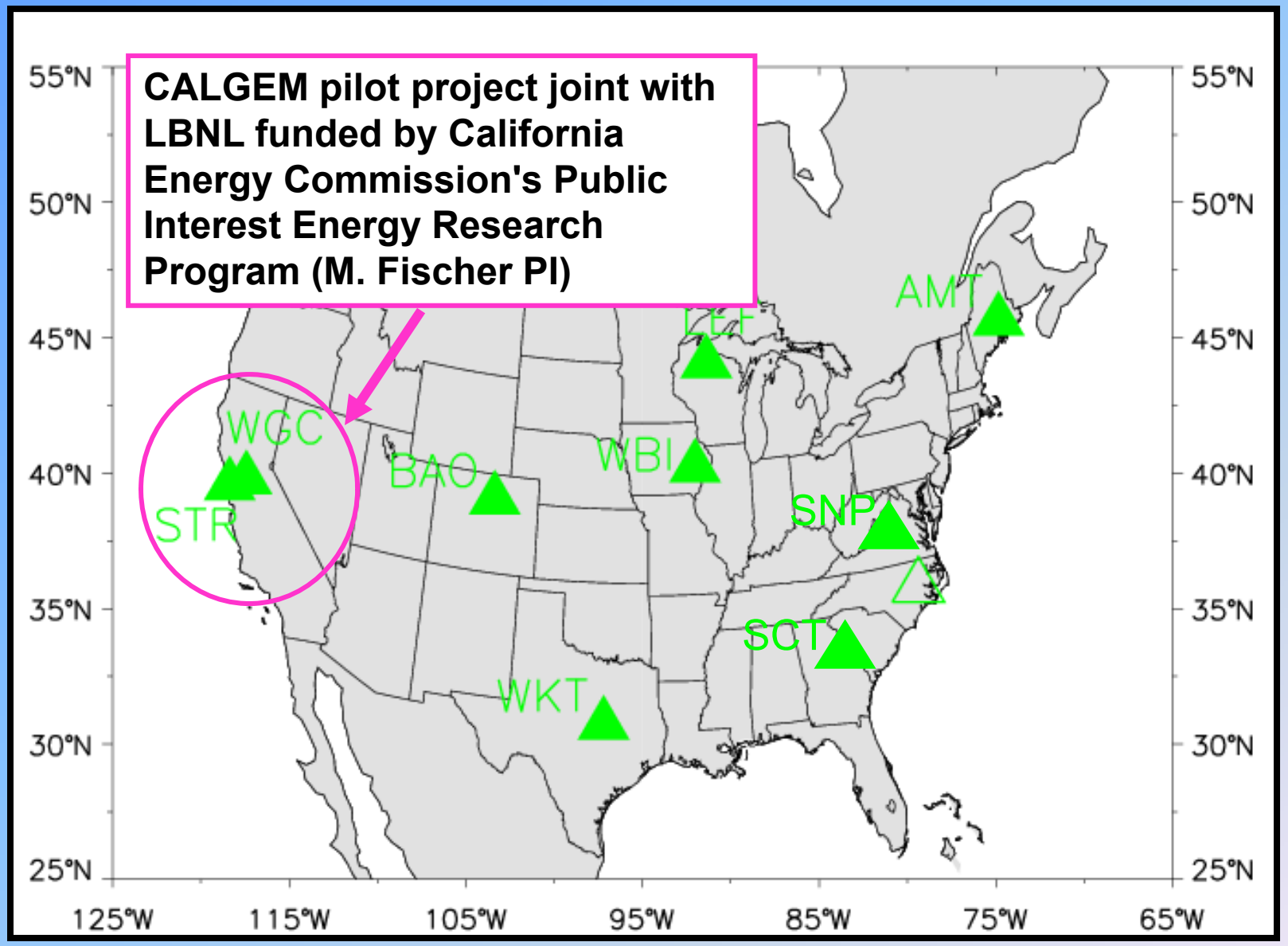


Strong anthropogenic influence

Surface uptake

Multiple species aid in quantitative source attribution for GHGs.


NOAA ESRL Tall Tower Network
55°N
50°N
45°N
40°N
35°N
30°N
25°N
125°W
115°W
105°W
95°W
85°W
75°W
65°W
AMT
LEF
WGC
BAO
WBI
STR
SNP
SCT
WKT


CALGEM pilot project joint with LBNL funded by California Energy Commission's Public Interest Energy Research Program (M. Fischer PI)
55°N
50°N
45°N
40°N
35°N
30°N
25°N
125°W
115°W
105°W
95°W
85°W
75°W
65°W
WGC
STR
BAO
WBI
AMT
SNP
SCT
WKT

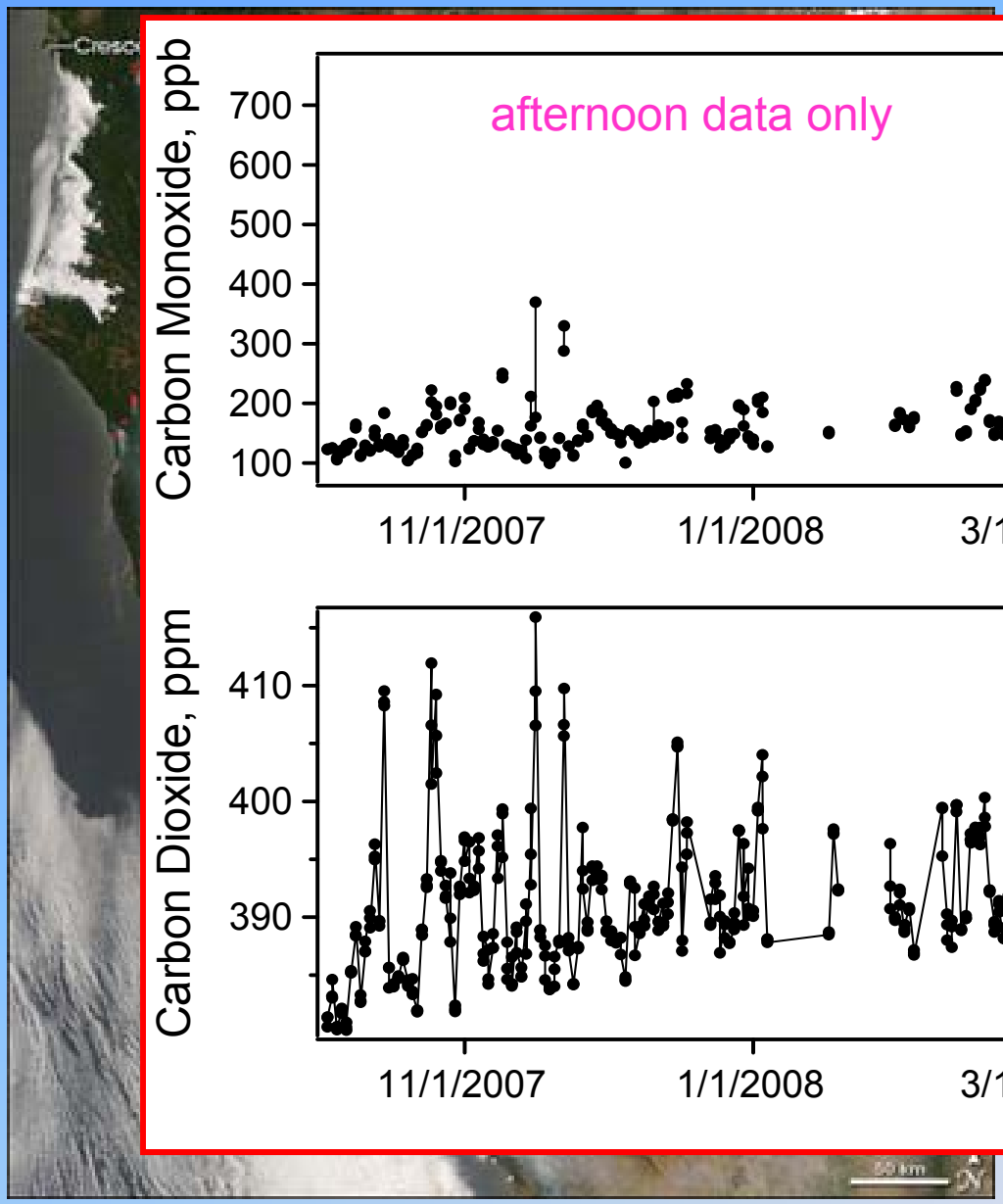
Fires in California: June/July 2008

Sutro Tower

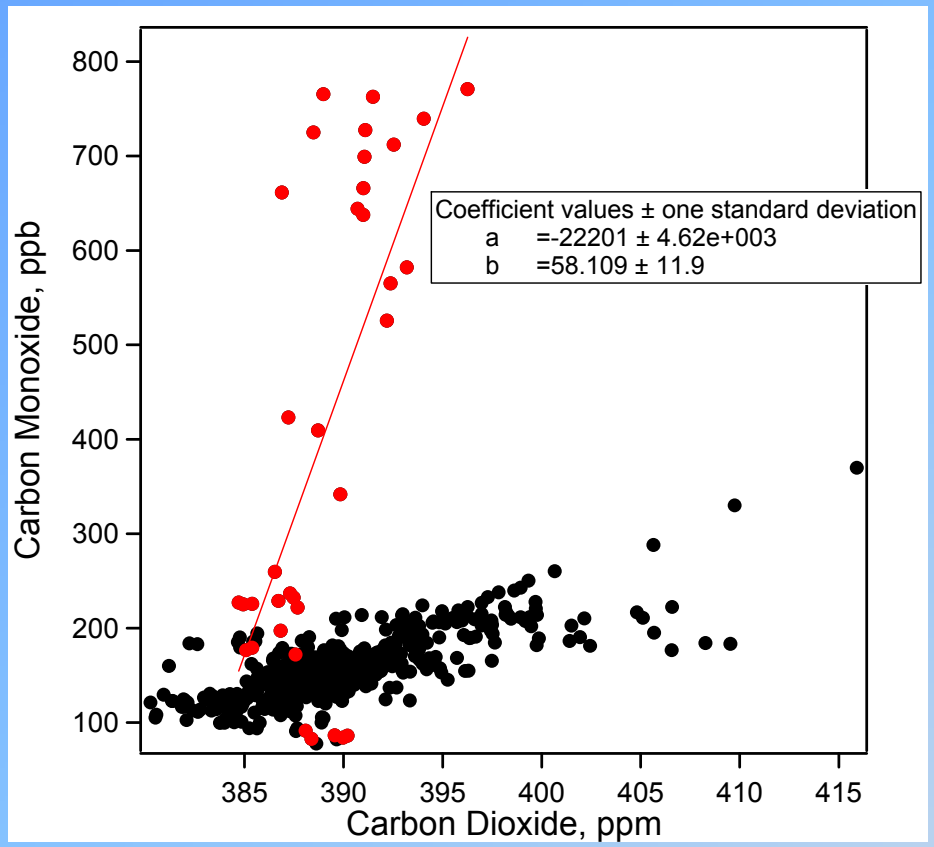
ESRL/LBNL tall tower site in Walnut Grove, CA

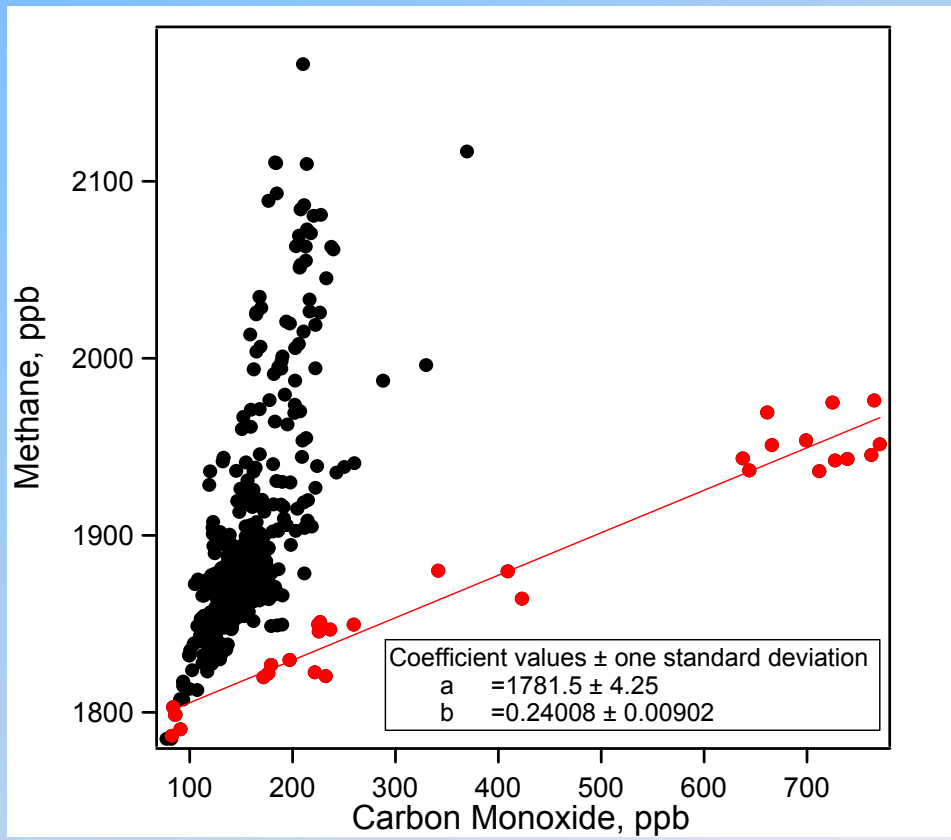
MODIS Image 6-27-2008

Fires in California: June/July 2008



Fires in California: June/July 2008





NOAA Tall Tower Measurement Systems

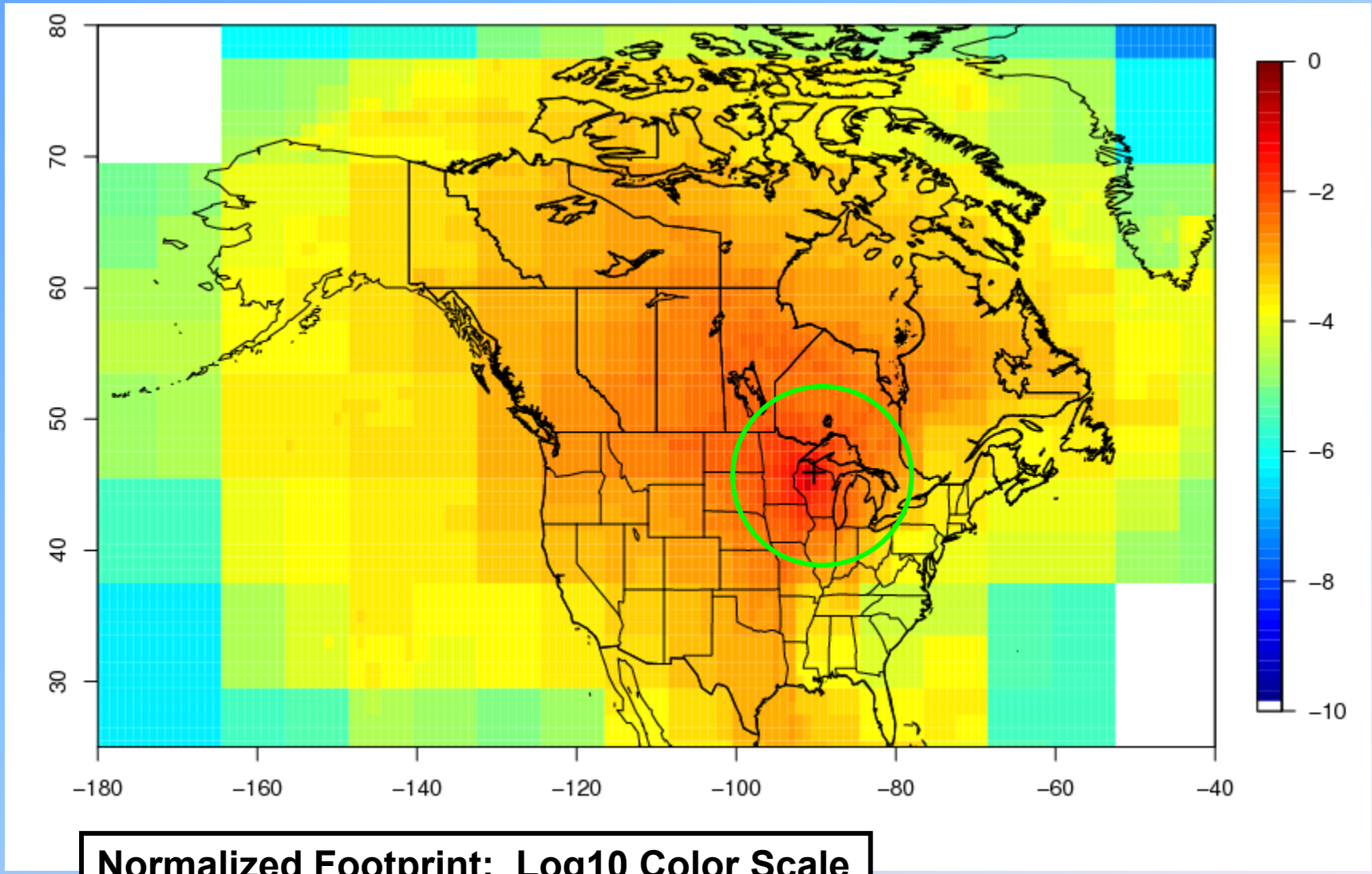
Nominal 3 levels: 30, 100, 500m AGL

- Semi-continuous CO_2
- Semi-continuous CO
- Automated Flask Sampler: one 12-pack per week
  - CO_2, CO, CH_4, N_2O, SF_6, Halocarbons, stable isotopes of CO_2, working to start $^{14}CO_2$ and $^{13}CH_4$ on select samples
  - Important part of QA/QC strategy
- Basic Meteorology: horizontal wind, air temperature, relative humidity, photosynthetically active radiation, rainfall, surface pressure

- CH_4 & CO_2 (Picarro Cavity Ring Down): Sacramento tower only (purchased for CALGEM)
- Radon-222: two sites

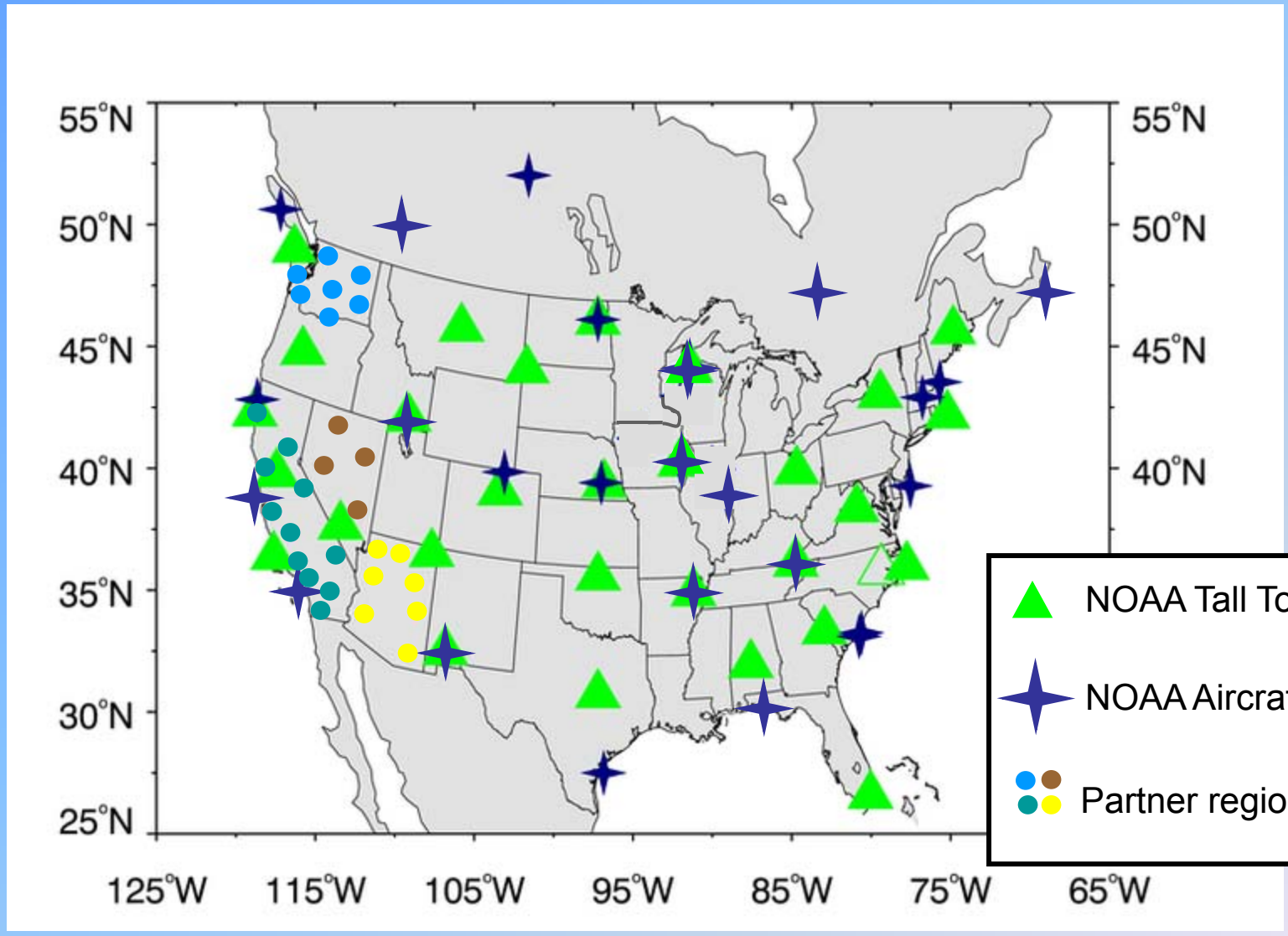
CO_2 precision better than 0.1 ppm (30-sec average)
CO precision better than 3 ppb (2-min average)
CH_4 precision better than 1 ppb (30-sec average)

Tall Tower Sampling Footprint

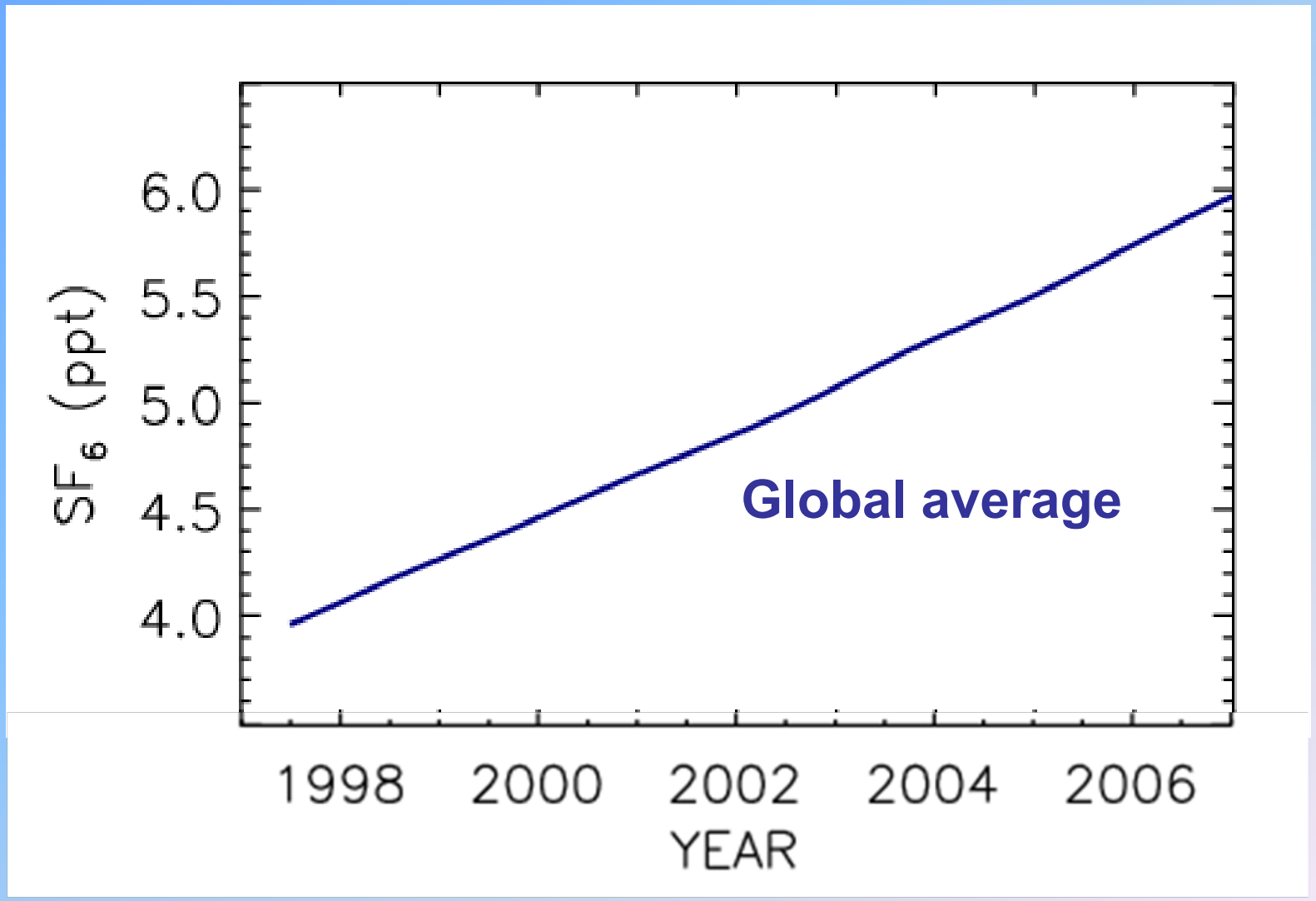


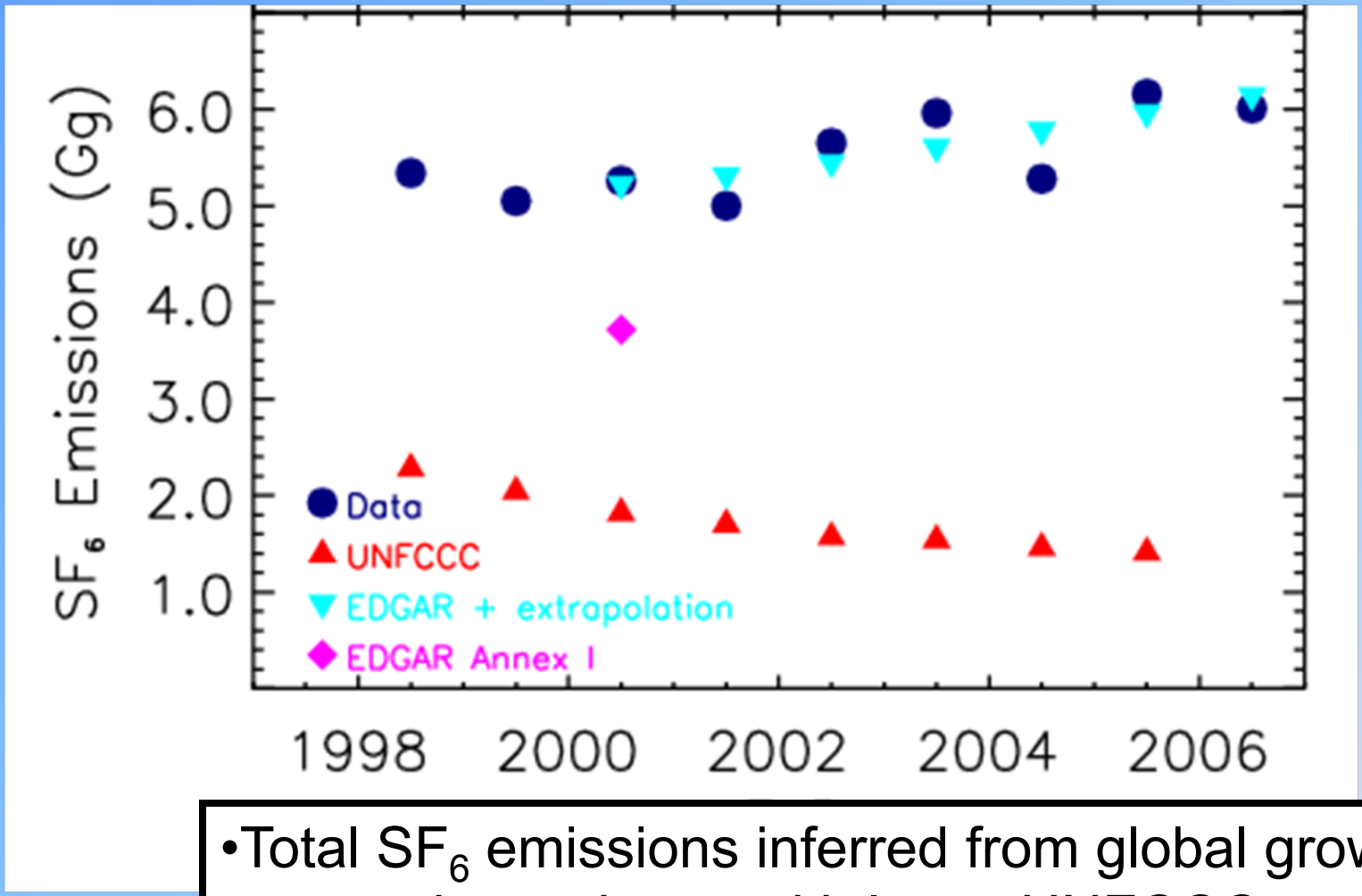
Normalized Footprint: Log10 Color Scale
Composite: MAY-JULY 2004 LEF, 19GMT

Hypothetical Future CarbonTracker Observing Network for North America



NOAA Network also tracks other greenhouse gases: e.g., SF_6

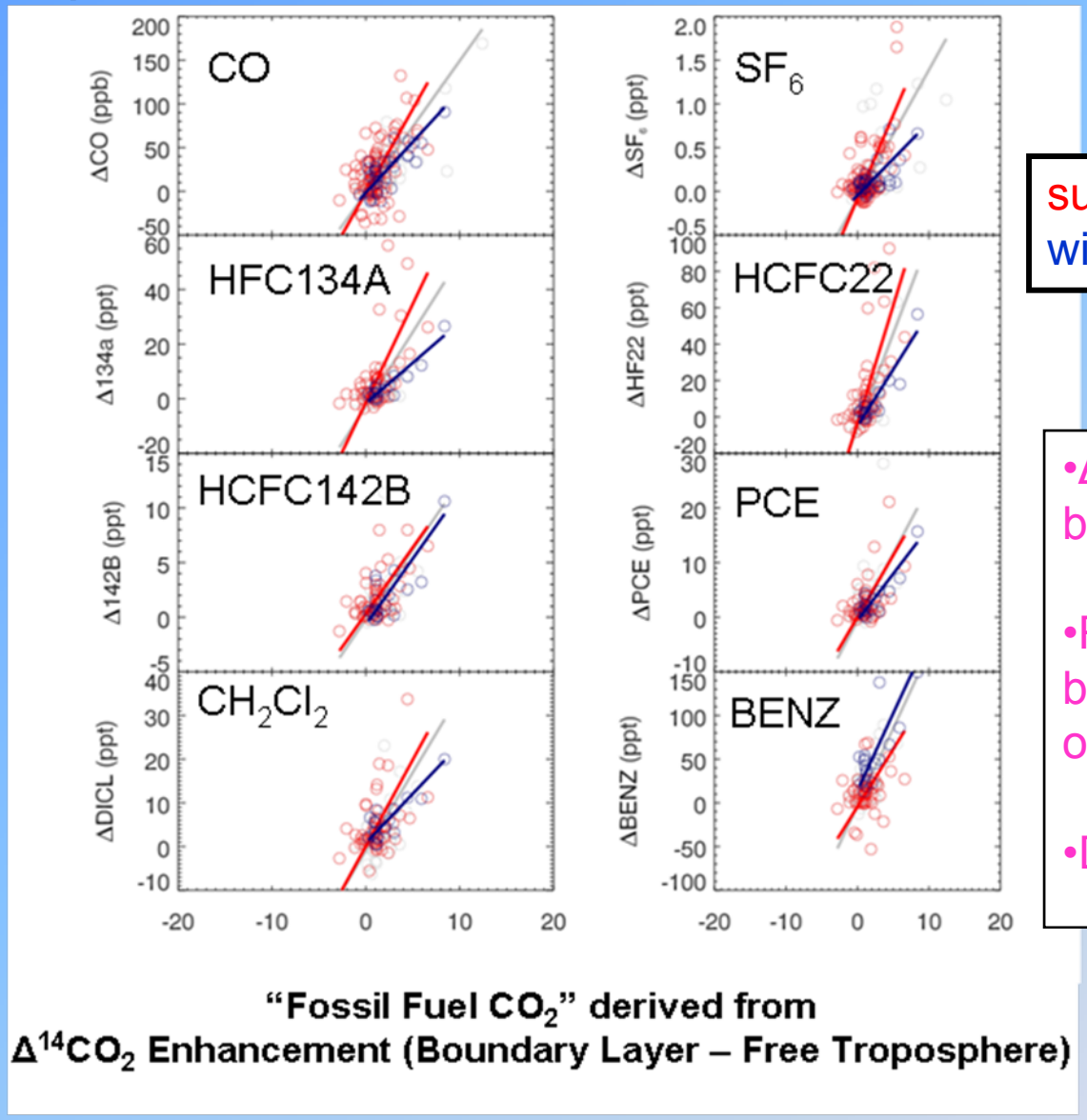




- Total SF_6 emissions inferred from global growth rate are inconsistent with latest UNFCCC Inventory (factor of 2-3)
- Long-lived gases with slow emission rates are an especially difficult inventory problem

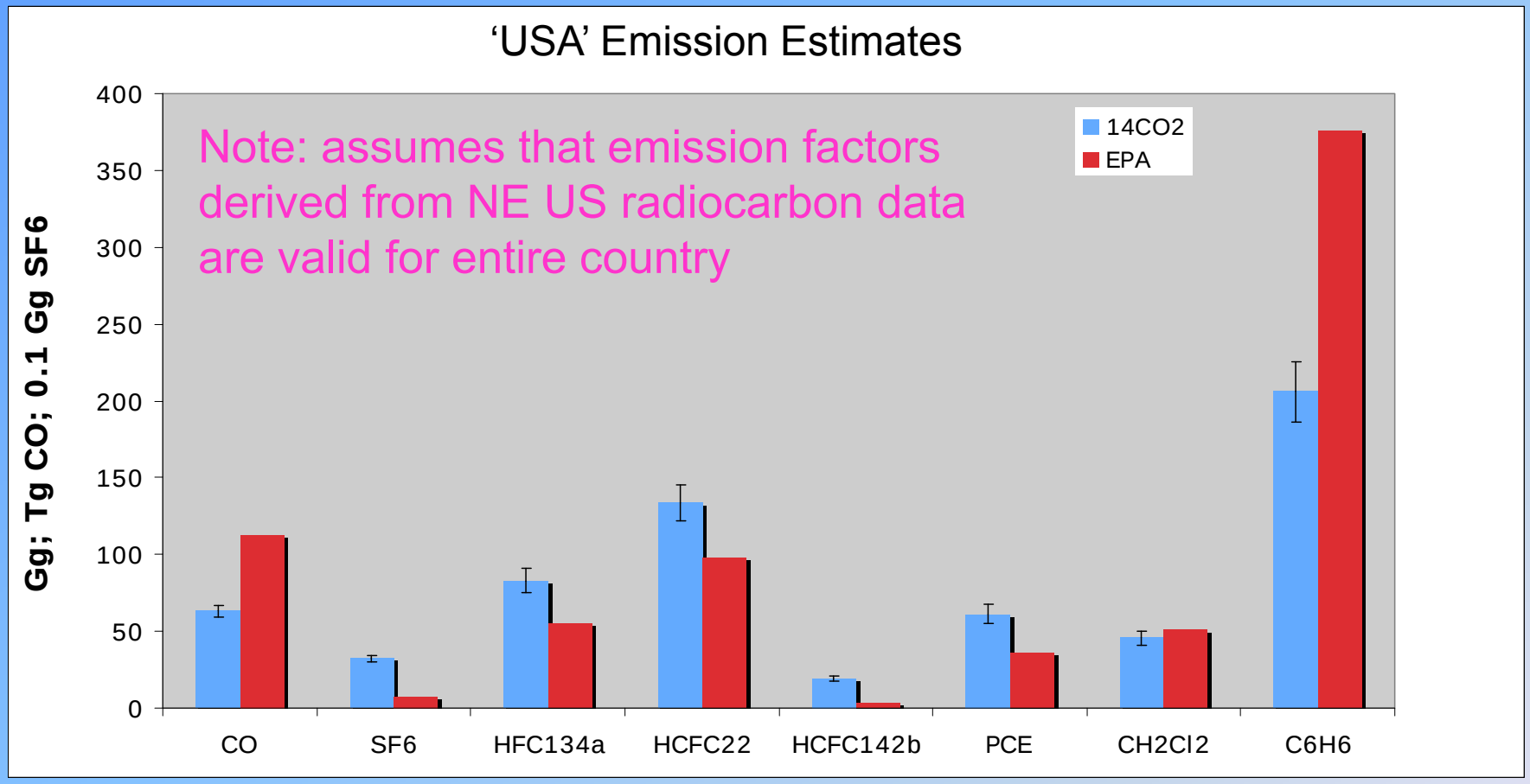
Courtesy of Molly Heller and Gabrielle Petron (CIRES) and Ed Dlugokencky (NOAA)

Radiocarbon measurements have the potential to improve "top-down" estimates of GHGs:



- $\Delta^{14}CO_2$ is insensitive to biological influences on CO_2
- Robust emissions ratios can be computed for a large suite of gases.
- Data are from Northeast US

Courtesy of John Miller (CIRES), Scott Lehman (INSTAAR) and Steve Montzka (NOAA)



- US EPA Report on "Inventory of US Greenhouse Gas Emissions and Sinks, 1990-2004, updated" for HFC134a, HCFC22, HCFC142b; 2006/2007 values
- US EPA NEI 2002 for CO, PCE, CH_2Cl_2, and C_6H_6
- INVENTORY OF U.S. GREENHOUSE GAS EMISSIONS AND SINKS: 1990-2006 (April 2008) USEPA #430-R-08-005 for SF_6

Courtesy of John Miller (CIRES), Scott Lehman (INSTAAR) and Steve Montzka (NOAA)

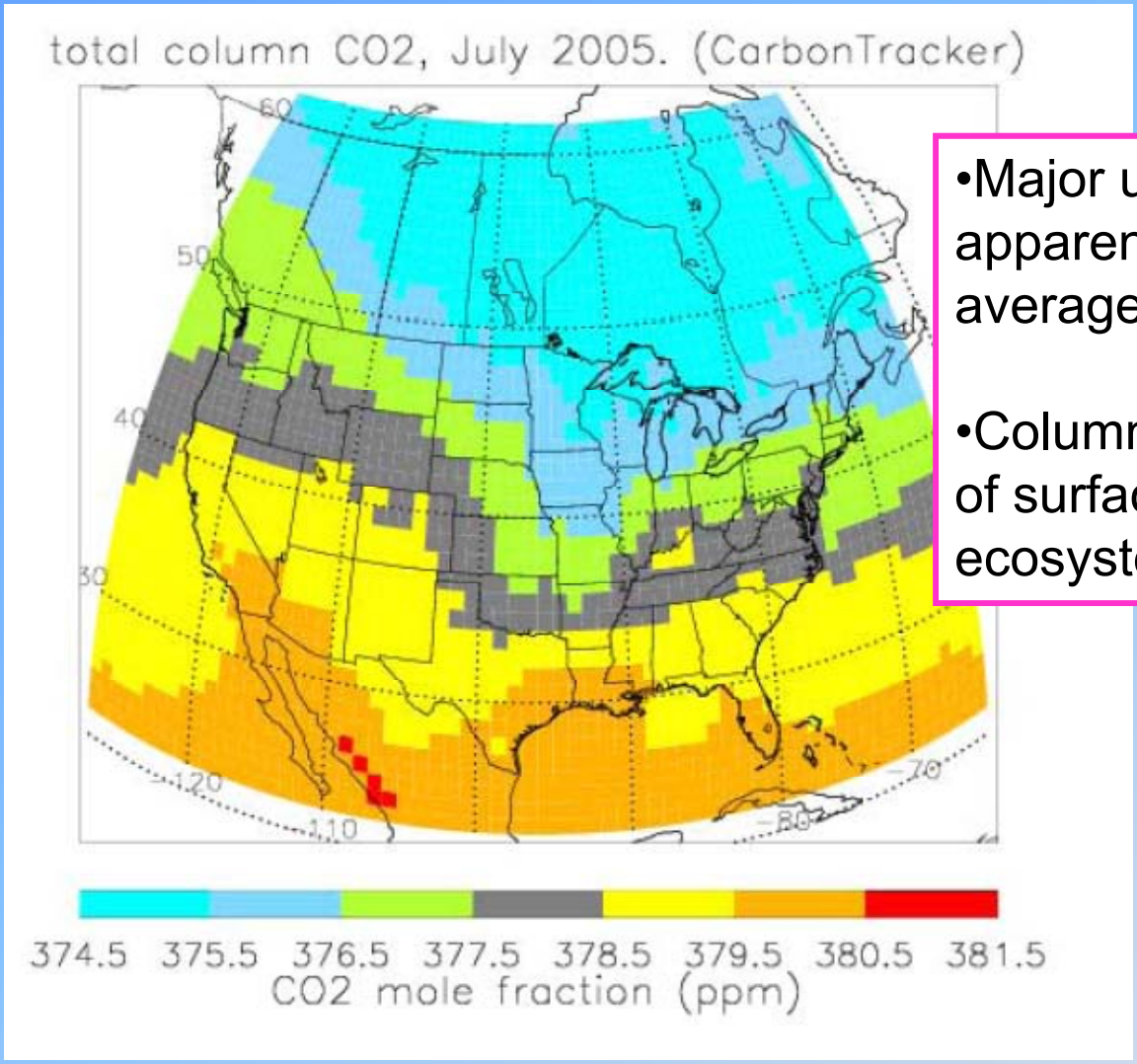
Summary Points

•Accurate tracking of GHG emissions using “top-down” methods is critically needed to monitor compliance in an international regulatory context.

•The precision and accuracy requirements for monitoring long-lived GHGs far exceed those for criteria pollutants e.g. Target accuracy for O_3 is ±1%, WMO recommended target for CO_2 is ±0.04% CH_4 is ±0.1%

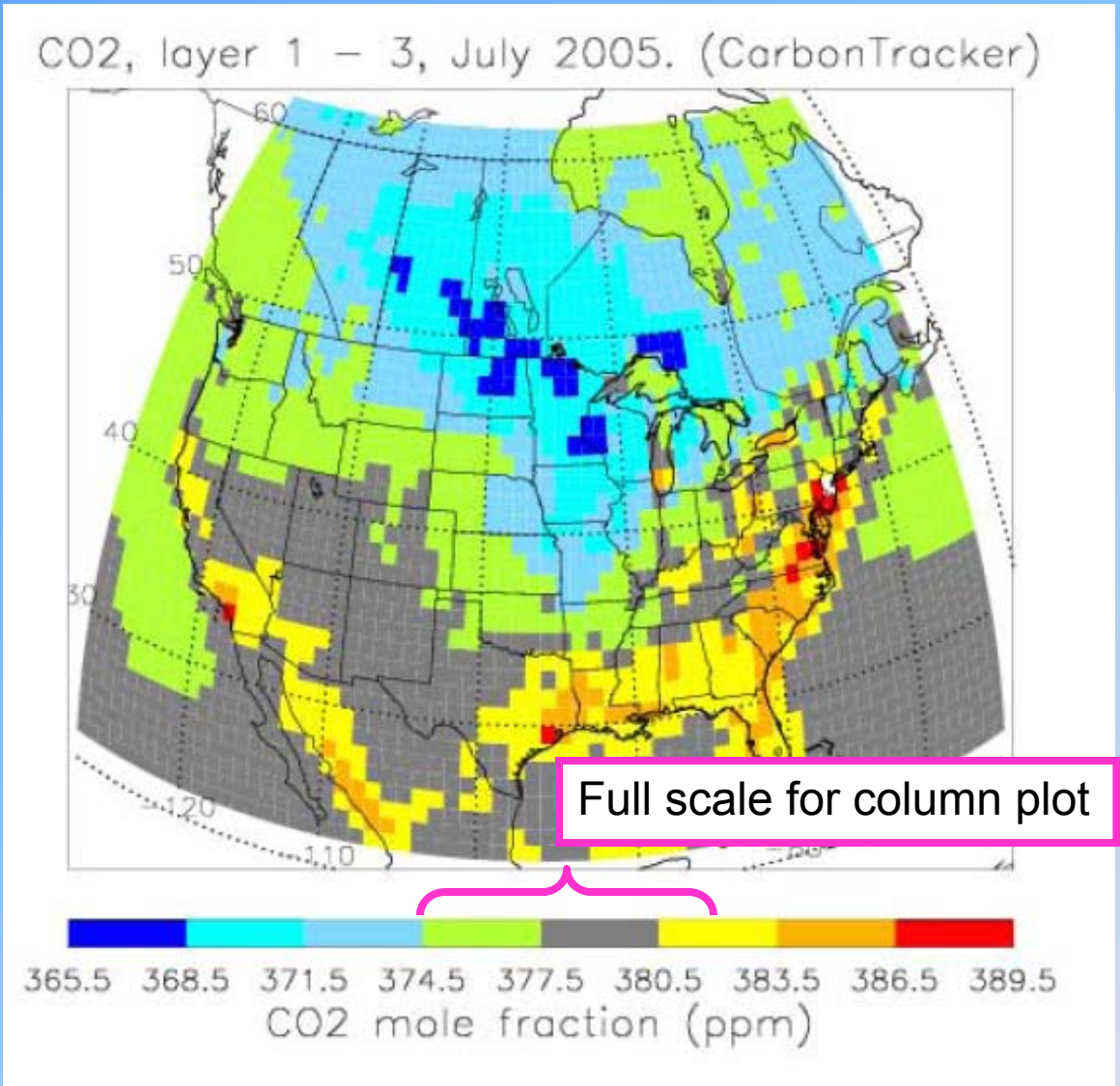
•NOAA has an established record of making highly precise and accurate measurements of all major GHGs, but the scope of the needed future monitoring effort greatly exceeds any single organization’s current capabilities.

The challenge for satellite-based CO_2 sensors:



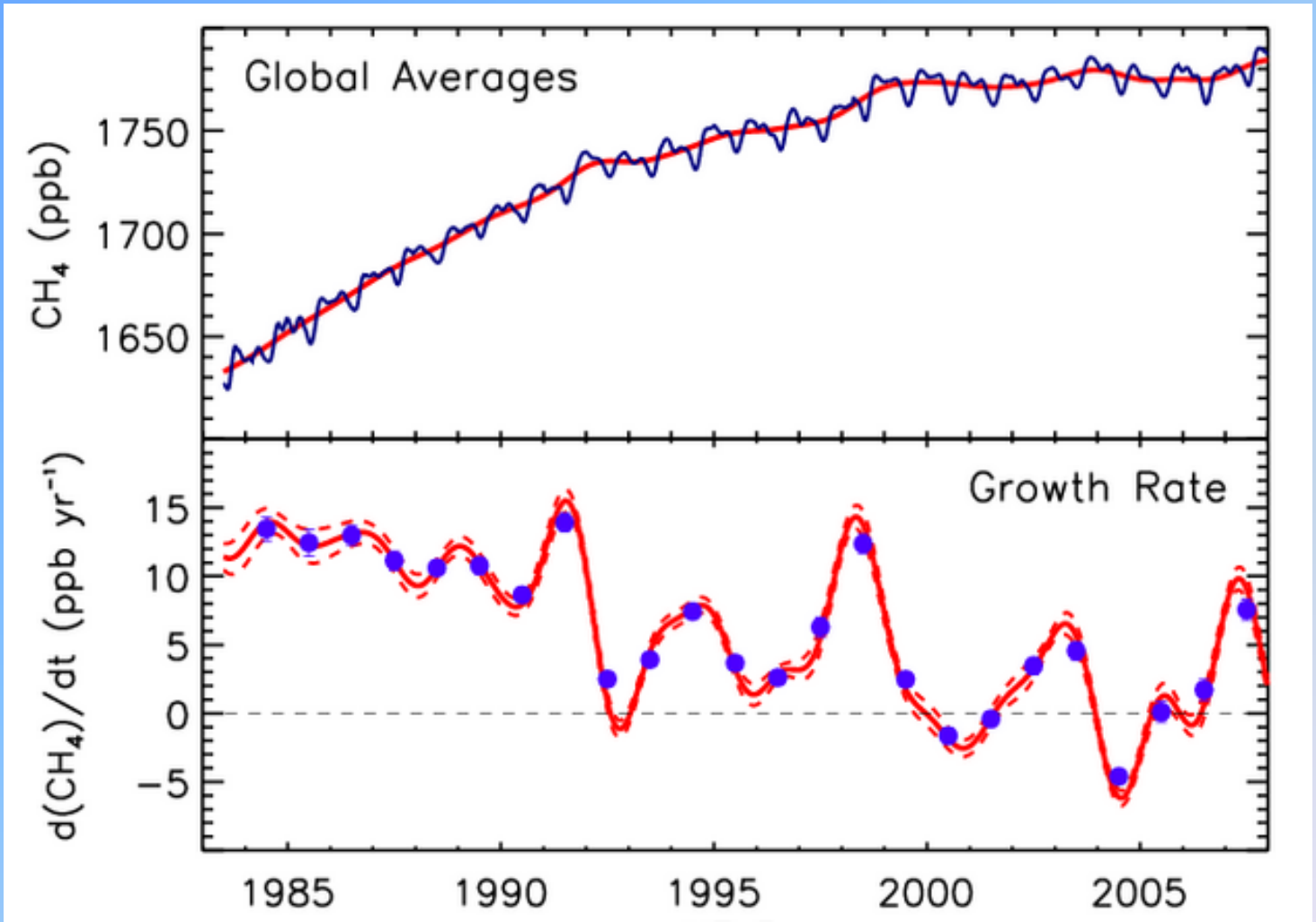
- Major urban centers not apparent in month-long average of total column CO_2.
- Column shows no evidence of surface uptake over active ecosystems

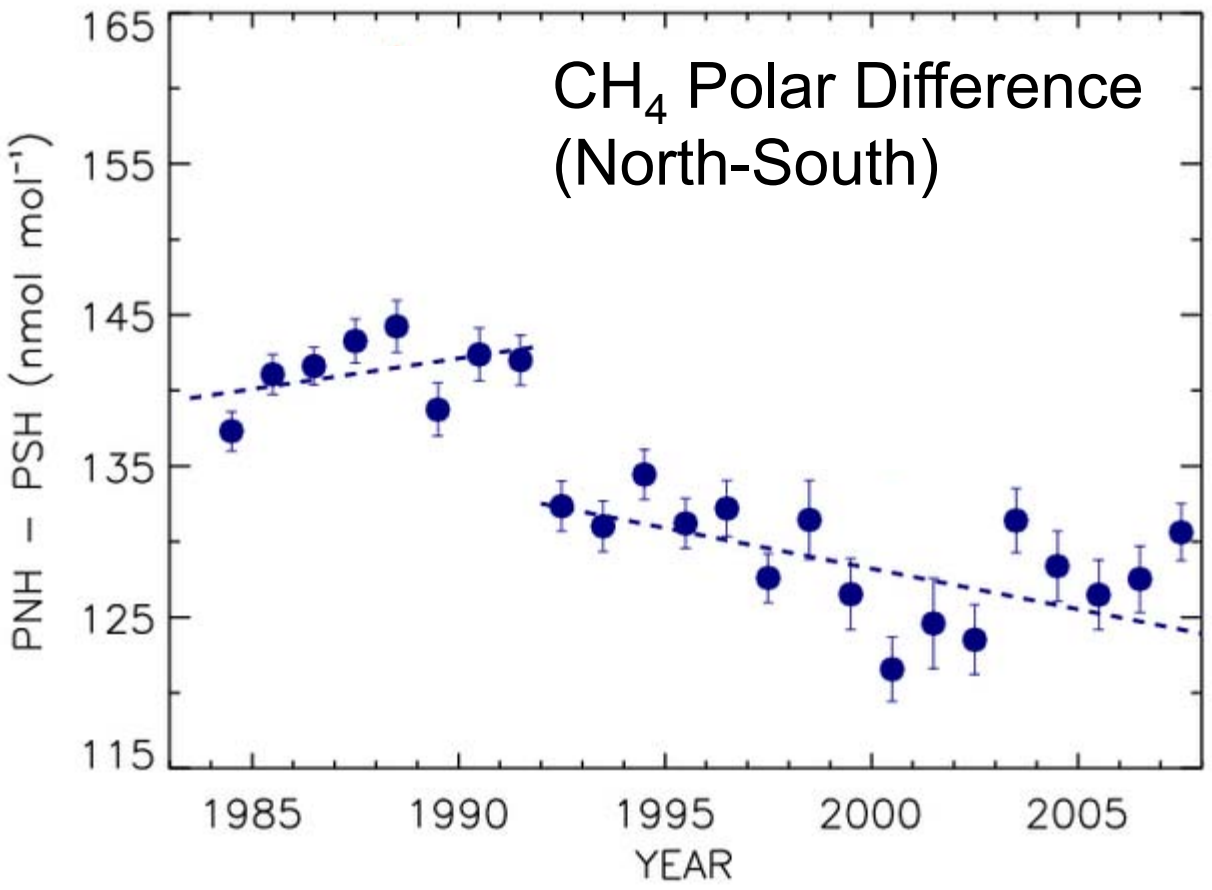
Signature of surface sources and sinks is diluted and indistinct for satellite column measurements



Source and sink patterns are the dominant features in the planetary boundary layer.

CH_4 global average and growth rate:



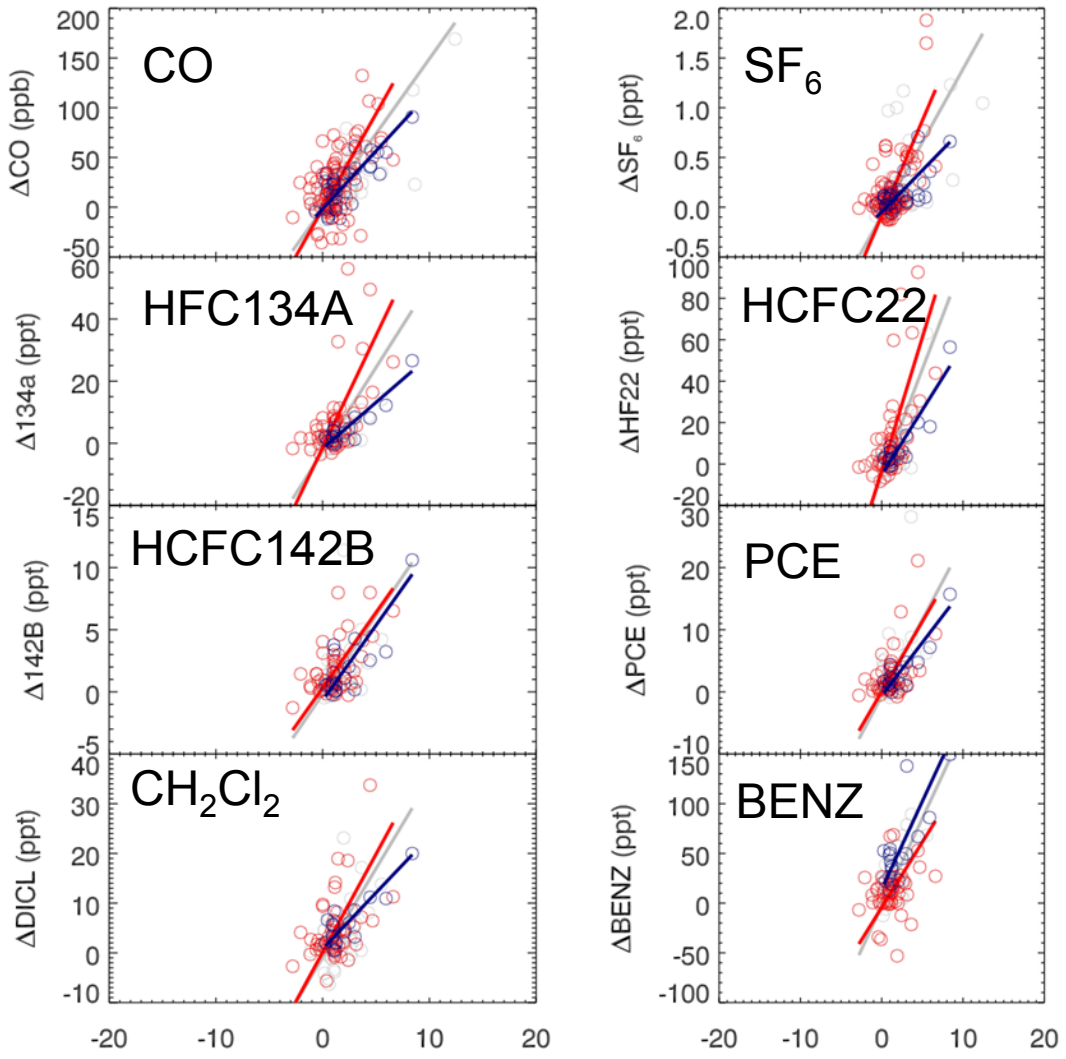


Change in CH_4 polar difference is consistent with major emissions reduction in former USSR.

INVENTORY OF U.S. GREENHOUSE GAS EMISSIONS AND SINKS: 1990-2006 (April 2008)
USEPA #430-R-08-005

Trends: Table 2.1

	TgCO2Eqiv	Gg (GWP=SAR value=23900)
1990	32.7	1.37
1995	28.0	1.17
2006	17.3	0.72



"Fossil Fuel CO_2" derived from
$\Delta^{14}CO_2$ Enhancement (Boundary Layer – Free Troposphere)

Sampling footprint for radiocarbon analysis: